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REPORT

FINAL REPORT

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Technology Evalua
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System (AIPS)

93-05223

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To

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and Engineering Center
Aberdeen, MD 21010

December 1992

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REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY	2. REPORT DATE DECEMBER 1992	3. REPORT TYPE AND DATES COVERED FINAL REPORT

4. TITLE AND SUBTITLE TECHNOLOGY EVALUATION FOR AN ADVANCED INDIVIDUAL PROTECTION SYSTEM (AIPS).	5. FUNDING NUMBERS DLA900-86-C-2045
6. AUTHOR(S) KASTNER, L. GREGORY; BROADWATER, JEFFREY W.; RUSCAK, JOSEPH M.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) BATTELLE COLUMBUS DIVISION 505 KING AVENUE COLUMBUS, OH 43201-2693	8. PERFORMING ORGANIZATION REPORT NUMBER CBIAC-SS-334
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) US ARMY EDGEWOOD RESEARCH, DEVELOPMENT AND ENGINEERING CENTER EDGEWOOD AREA ABERDEEN PROVING GROUND, MD 21010-5423.	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT DISTRIBUTION UNLIMITED, APPROVED FOR PUBLIC RELEASE.	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

THE OBJECTIVE OF THIS TASK WAS TO IDENTIFY, COLLECT DATA AND EVALUATE TECHNOLOGIE THAT, IN THE FUTURE, WILL PROVIDE ENHANCED PROTECTION AND PERFORMANCE FOR AN ADVANCED INDIVIDUAL PROTECTION SYSTEM (AIPS). THE EVALUATION ASSESSES THE LONG TERM EXPECTATIONS OF THESE TECHNOLOGIES, IDENTIFIES RESEARCH AND EQUIPMENT NEEDED TO MATURE THESE TECHNOLOGIES, AND PROVIDES A SKETCH OF AN AIPS INCORPORATING SEVERAL OF THE MORE PROMISING TECHNOLOGIES. THIS DOCUMENT WILL SERVE AS A TECHNOLOGY BASE FOR FUTURE DEVELOPMENTAL PROGRAMS TO IMPROVE ASPECTS OF THE RESPIRATORY PROTECTION SYSTEM.

14. SUBJECT TERMS ADVANCED INDIVIDUAL PROTECTION SYSTEM (AIPS) RESPIRATORY PROTECTION RESPO 21	15. NUMBER OF PAGES 65
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTR
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)

Final Report

Contract Number DLA 900-86-C-2045, CLIN 0002 LE

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Technology Evaluation for an Advanced Individual Protection System (AIPS)

To

U.S. Army Edgewood Research, Development and Engineering Center
Aberdeen, MD 21010-5423

December, 1992

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Prepared by:

L. Gregory Kastner
Jeffrey W. Broadwater
Joseph M. Ruscak

BATTELLE
505 King Avenue
Columbus, OH 43201-2693

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1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Army Edgewood Research, Development, and Engineering Center (ERDEC) is scheduling a long term respiratory protection development program for an Advanced Individual Protection System (AIPS). The program is designed to provide a high level respiratory protection system for the year 2020 and beyond. The primary goal of the program is to provide individuals with enhanced protection and performance while wearing respiratory protection. A technology workshop conducted for the Respiratory Protection System 21 (RESPO 21) identified many of the technology areas that needed to be investigated.[1] In order to orient early research activities, a more detailed investigation into technology areas related to respiratory protection was needed.

1.2 OBJECTIVE

The objective of this task was to identify, collect data and evaluate technologies that, in the future, will provide enhanced protection and performance for an AIPS. The evaluation assesses the long term expectations of these technologies, identifies research and equipment needed to mature these technologies, and provides a concept sketch of an AIPS incorporating several of the more promising technologies. This document will also serve as a technology base for future developmental programs to improve aspects of the respiratory protection system.

2.0 APPROACH

The evaluation began with an initial list of technologies developed from the IPE design workshop for RESPO 21, the Respiratory Protection Equipment Front End Analysis,[2] and input from the client.[3] The list was iteratively updated from the following sources.

- input from Battelle's technical staff who specialize in technology areas related to AIPS
- contact with national labs, academia, and government R & D facilities
- literature searching

The literature searches continued as new technologies were identified. The technology evaluation and selection began upon completion of the literature searches. Figure 1 shows the overall approach of the project. Sections 2.1 through 2.3 discuss the data gathering process in more detail. Sections 2.4 and 2.5 discuss the technology evaluation and selection process.

2.1 TECHNOLOGY AREAS

In order to organize literature searching and contact with researchers, technologies were categorized into the following general areas:

- respiratory protection
- thermal management
- vision/optics
- communications
- system controls

The most important technology area of the evaluation was respiratory protection. However, since technologies in the other areas will significantly impact the design of a respiratory protective system, all technology areas were researched with an equal level of effort.

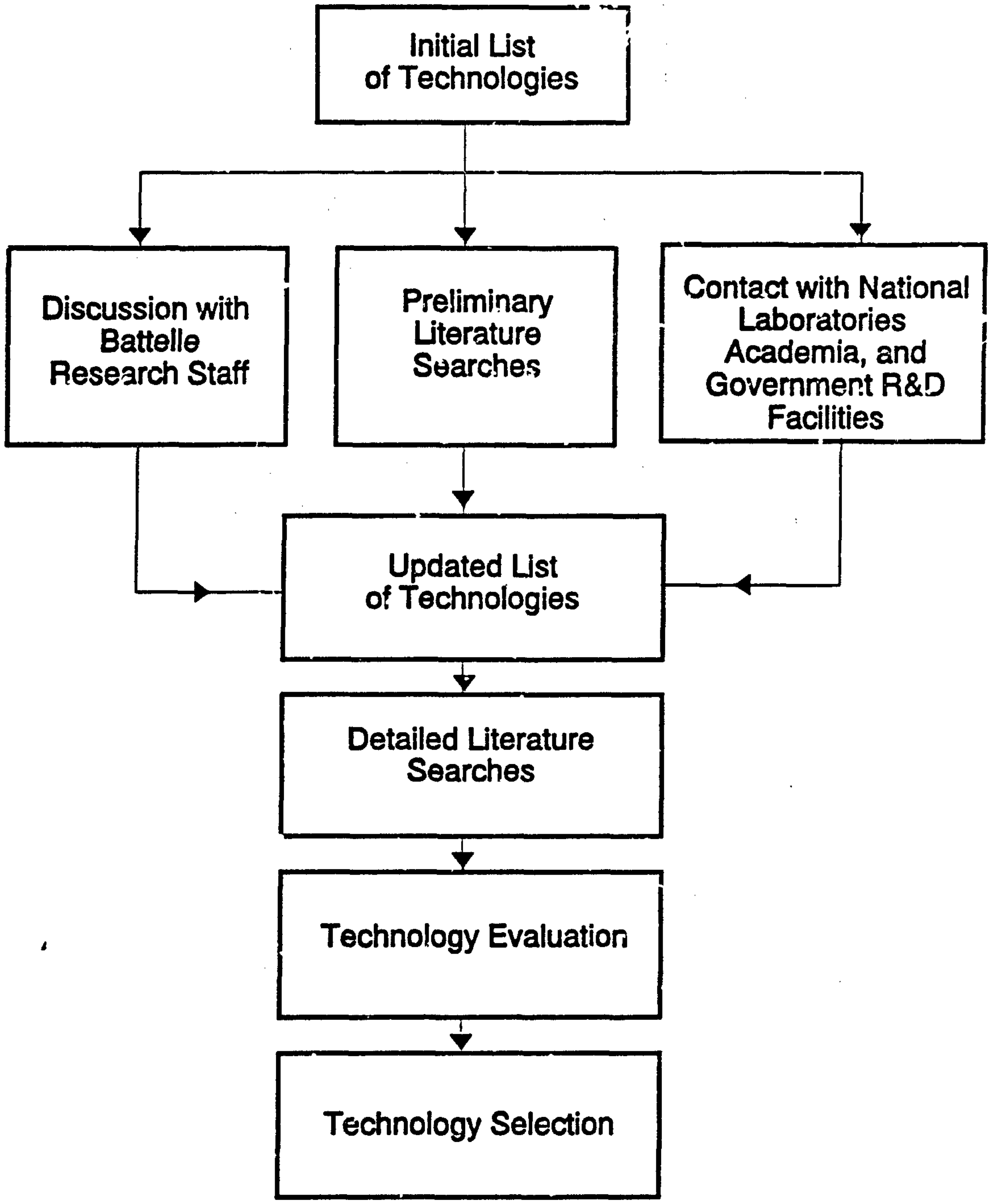

Figure 1. Approach

2.2 TECHNOLOGY COMMUNITY CONTACT

Various government laboratories, academia and industrial research facilities were contacted in efforts to identify new technologies, identify other points of contact (POC's) and gather information on technologies applicable to AIPS. Government directories and federal lab locator services were used to identify key POC's. We also contacted organizations outside the military that we felt would be involved with individual protection and life support equipment development, such as space exploration, underwater research, and medical research. Military organizations were contacted on a limited basis to confirm their specific areas of interest and to prevent duplication of research efforts.

A list containing names, addresses, and phone numbers of all organizations contacted during the evaluation is presented in Appendix A, which also includes Battelle's contacts and POC's not contacted for political reasons. Early in the project, contact with the technology research community was not as fruitful as we had anticipated, however substantial enough to enable us to identify key researchers within the various technology areas, who, later in the project assisted with identifying needs for developing technologies.

In addition to telephonic data gathering, the following visits were made to acquire information on AIPS related technologies.

1. Hines VA Hospital Rehabilitation R&D Center, Hines, Illinois

   POC: Dr. John Trimble

   TOPICS:
   - virtual reality
   - voice recognition
   - 3-D audio
   - ultrasonic sensing
   - video graphics

2. Soldier as a System Symposium/Exposition

   POC: Carol Fitzgerald (NRDEC)

   TOPICS:
   - helmet mounted displays
   - IR/thermal imaging
   - microclimate cooling

POC: Tom Hafer/Dick Urban (DARPA)

TOPICS:
- helmet mounted displays
- voice recognition (for security)
- liquid crystal displays
- multimedia communications

POC: James Schoening (CECOM)

TOPICS:
- pocket-sized computing
- global positioning systems
- helmet mounted displays
- future communications

POC: Selma Nawrocki (BRDEC)

TOPICS:
- individual power
- batteries/engines/fuel cells

POC: Wes Goodwin (NRDEC)

TOPICS:
- microclimate cooling
- vapor compression cycles
- individual power

2.3 LITERATURE SEARCHES

The literature searches began by reviewing Battelle in-house sources for useful reports. This included a library developed to support a mask database Battelle operated databases and information sources were also searched for overview/future planning information. These sources include the Chemical Warfare/Chemical and Biological Defense Information Analysis Center (CBIAC) and Tactical Technology (TACTEC) information center. These sources were not searched for specific technologies since the type of technology information we were interested in is best found through basic research type journals and science oriented databases (contained in DIALOG).

Prior to starting the searches for basic technology information, the Defense Technical Information Center (DTIC), CBIAC, TACTEC, and DIALOG (NTIS and COMPENDEX) databases were searched using combinations of the following keywords: future, advanced, individual, protection, clothing, battlefield, military, space, and medical. These searches did not yield many "hits" but did identify reports on state-of-the-art technologies, which aided in establishing a data base for clear distinction between "current" and "future" technologies.

Online literature searches were completed through DIALOG. Specific files contained in the DIALOG database and the technology areas searched are shown in Table 2-1.

Table 2-1. DIALOG Database Searches

TECHNOLOGY AREA	DIALOG FILES					
	4	8	161	233	238	636
Respiratory Protection		X	X			X
Thermal Management		X	X			X
Vision/Optics	X	X		X	X	X
Communications	X	X		X	X	
System Controls	X	X		X	X	

4: INSPEC
8: COMPENDEX
161: NIOSHTIC
233: MICROCOMPUTER INDEX
238: ROBOTICS/ARTIFICIAL INTELLIGENCE
636: SCIENCE NEWSLETTER

These files were selected from a DIALOG directory due to their broad science, engineering, and technical content. The following databases were searched for respiratory protection and thermal management technologies only.

- Health and Safety Science Abstracts (HSSA)
- Commerce Business Daily (CBD)
- World Patents Index (WPI)
- NASA RECON

Appendix B contains brief descriptions of databases searched for AIPS technologies.

We conducted technology searches first using broad terms then using specific technologies, with the following search strategy. For the broad searches, the entire text within a database was searched using words shown in the left columns of Tables 2-2 to Table 2-6. When necessary, the number of hits were reduced by specifying where words occurred in the database (i.e. abstract, title, within two words of each other, etc.). Generic terms were added to reduce the number of hits to a

manageable level (as needed). The specific technology searches were conducted in a similar manner using the technologies shown in the right hand columns. The following words were used to limit the number of hits per technology to approximately 25: futur$, advanc$, and simulat$. All database searches were limited to the past five years.

In addition to computer assisted database searching, we conducted manual literature searches of common research, science, and engineering journals. The following journals were reviewed for articles that may not have been identified by the database searches.

Artificial Intelligence
Aviation Space and Environmental Medicine
Aviation Week and Space Technology
Design Facts
Design News
Heat Transfer Engineering
IEEE Proceedings and Journals
International Journal of Robotics Research
Journal of Imaging Science and Technology
Laser Focus World
Machine Design
Mechanical Engineering
Medical Equipment Designer
Optical Engineering
Optics and Laser Technology

The table of contents of volumes within the past two years were reviewed for applicable articles.

Table 2-2. Searches on Respiratory Protection Technologies

Broad	Specific
Oxygen Generation Life Support	Oxygen Rebreathing Oxygen Generation from: Carbon Dioxide Water (vapor) Electrolysis Plant/Algae
Respirat$ Oxygen$	Bioregenerative Support System Hyperthermal Atomic Oxygen Generation Surrogate Lungs Hemosponges Thermo Electric Conversion with Ion Conductors Controlled Ecological Life Support System Artificial Gills

Table 2-3. Searches on Thermal Management Technologies

Broad	Specific
Air Cooling	Microenvironmental Heating or Cooling
Liquid Cooling	Free Piston Method for Microclimate Cooling (MCC)
Liquid Heat Sink	Man-portable Microclimate Conditioning
Convective Heat Removal	Circuit Coolant
Conductive Heat Removal	Ice Water-Cooled Vest
	Phase-Change Materials
Environment$	Radioactive Heat Removal (Cold-Plate)
Control$	Heat Pipes
Cool$	Thermoelectricity

Table 2-4. Searches on Vision/Optics Technologiess

Broad	Specific
Three Dimensional	Image Intensifier Tubes
Computer Scanning	Head Mounted Displays
Circuit Model of Human Retina	Scanning Mirrors
Photo Detector and Motion	Intelligent Photosensors
Map Processing	3-D Imaging
Analog Processing	Geometric Reasoning
Neural Networks	Virtual Reality/Display
Optical Sensor	Cyberspace
Target Acquisition	Electro-Chromic Polymers
	Stereo Vision
Optic$	Liquid Crystal Displays
Vis$	Fiber Sensors
	Adaptive Resonant Architecture
	Charge Coupled Devices
	Bistatic Radar
	Human Radiation

Table 2-5. Searches on Communication Technologies

Broad	Specific
Scanning Technology (Computer)	Voice Recognition
Analog to Digital Data Conversion	Binaural Hearing
Communication Networks	Binaural Headphones
Acoustic Sensors	Wireless LAN
3-D Audio System	Modulated Laser Light
Infrared (IR) Transmission	Audio Digitization
Communic$	
Aud$	
Hear$	

Table 2-6. Searches on System Control Technologies

Broad	Specific
Microelectronics	Data Processing
Ultrasonic Devices	Neural Networks
Miniature Computer Screens	Optoelectronics
Micromachining	Fuzzy Logic
Artificial Intelligence	Object Processing
Control$	
System$	

2.4 AIPS REQUIREMENTS

In future contingency operations, initially deployed forces may be small in number and, at least at first, not fully supported by heavy forces. The effectiveness of these initially deployed troops must be enhanced by every means that technology can provide. Even with continuing technological progress, the operation of every Army system will continue to involve the human. No matter how sophisticated the operation of a system, human control will remain essential. Also, human interpretation of information will continue to be a major factor in system performance. Because the individual soldier in the future will be asked do more, and to do it with more complex systems, enhanced protection and performance will become more important than ever.

With the Army's recent emphasis on treating the individual soldier as a system, as outlined in the Army's STAR 21 report,[4] care must be taken in considering technologies which ensure that the following conditions can be met:

- The functions and data required for each subsystem within the entire system are available from other subsystems or from outside the system.
- All internal and external interfaces operate correctly.
- The system can function correctly in its likely environments without interference to or from other subsystems.
- Failure of subsystems will not result in failure of the soldier's entire system and will not critically affect the soldiers ability to execute the mission at hand.

Natick Research, Development, and Engineering Center (NRDEC) is leading an effort that demonstrates the "soldier as a system" concept: Soldier Integrated Protective Ensemble (SIPE), which consists of thee major subsystems of the SIPE: integrated headgear, advanced clothing, and microclimate conditioning/power.[5-8] An Advanced Technology Demonstration (ATD) is underway to demonstrate the modular concept and integration of subsystems. The objective of the SIPE program is to develop, fabricate, and demonstrate an integrated, modular, head-to-toe individual fighting system which will afford improved combat effectiveness while providing the individual soldier balanced protection against multiple battlefield hazards. SIPE will integrate state-of-the-art technologies to improve lethality, command and control, mobility, survivability, and sustainment.

The SIPE ATD will support 6.3b development of the Block 1 (next generation) system: The Enhanced Integrated Soldier System (TEISS). TEISS, like SIPE, is a modular head-to-toe fighting system designed to balance mission performance and protection by viewing the soldier as a total system. TEISS will transfer those technologies and capabilities successfully demonstrated in the SIPE ATD, into full scale development. The major components of TEISS for the individual ground soldier are: an advanced clothing subsystem, integrated headgear system, individual soldier computer, and objective family of small arms. TEISS's 6.3b development will commence FY94, 6.4 development FY97, and fielding FY99.[9]

Technologies being considered for the SIPE/TEISS are near-term, developmental technologies that meet current Army requirements. Technologies for AIPS will need to meet future requirements, which have not been established because battlefield threats in the year 2020 are unknown at this time. Thus, evaluating AIPS' technologies against today's requirements is not practical. However, general performance criteria can be used as guidelines for selecting various technologies, as presented below.

Long-range integrated systems such as AIPS must consider NBC protection and interface requirements with battlefield hardware. This planning must consider:

- IPE Integration Strategies
- System Integration
- Modular Design Techniques
- Environmental and Operational Adaptability
- Performance Enhancement
- Multiple Threat Protection
- Miniaturized and Lightweight Components
- Low Power Consumption
- Minimization of Physiological/psychological Burden
- Producibility/Manufacturability

Specific issues associated with each AIPS technology area are shown in Table 2-7. The respiratory protection equipment FEA overview, RESPO 21 design goals, and SIPE design goals were used to develop these selection guideline criteria.

Table 2-7. AIPS Technology Selection Guidelines

Technology Area	Issues
Respiratory Protection	Duration of operation Unknown threat Breathing resistance Moisture control
Thermal Management	Degradation in performance (physiology/psychology) Heating and cooling for comfort Heat signatures Skin contact hazards
Vision/Optics	Eye protection Field of view Enhanced vision in multiple environments Real time image processing Identification of friend or foe
Communications	Networking as well as immediate surroundings Directional sensing (positioning) Range detection Auditory protection
System Controls	Integration of subsystems Data processing limitations User and sensor feedback Electromagnetic interference Heat and noise signatures (power source) Cooling of microelectronics

2.5 TECHNOLOGY ANALYSIS

Technologies considered applicable for AIPS were analyzed for future applications, current limitations, and developmental risk. A valid quantitative comparison between technologies was not possible because of variations in technology parameters, potential applications, research needs, and stages of development associated with each technology. Thus, a more subjective analysis was used to

assess the risk of developmental technologies. The matrix presented in Table 2-8 defines the levels (low, medium, and high) of risk for specific time frames (near, mid, far) of development. For this evaluation, development time refers to the amount of time needed to mature a technology for impleme- ation with an AIPS. A comparative discussion of technologies is presented later in Section 4.0.

Table 2-8. General Technical Risk Guidelines

To Full Scale Development	Low Risk	Medium Risk	High Risk
Far-Term (> 15 Years)	Technology well understood. Proof of principle demonstrated, but application concept definition and complete system engineering required.	Technology new but understood. Early experiments hold some promise. Significant engineering effort needed.	Theory not fully understood or developed. Basic research being conducted.
Mid-Term (6-15 Years)	Technology established. Application concept defined and proof of principle successful. Engineering required.	Technology has been partially tested. Application concept needs further definition.	Proof of principle demonstrated only in part. Application concept needs further definition. Engineering and productivity issues not defined.
Near-Term (0-5 Years)	Technology applications exist in some systems. Component application proven, but integration required. Producibility proven.	Proof of principle demonstrated. Engineering solutions to design and producibility uncertainties identified.	Proof of principle demonstrated. Concepts to apply technology defined, but not tested. Major engineering needed.

3.0 DESCRIPTION OF TECHNOLOGIES

This section lists and describes specific technologies identified during the evaluation. Subsections are organized according to the five major technology areas discussed in section 2.1. A summary table at the beginning of each of the five subsections lists and briefly describes technologies discussed within that section. The table also identifies how each technology was treated during the evaluation. Several technologies within each technology area were not considered in the evaluation because they are being researched under other military programs. A few technologies were impractical for AIPS application, thus were not considered in the evaluation, but are described briefly at the end of each technology area subsection. Each technology area has a separate reference list contained in Appendix C. For convenience, references were letter-coded as follows:

R - respiratory protection
T - thermal management
V - vision/optics
C - communications
S - system controls

Figures and diagrams used to describe technologies are contained in Appendix D.

3.1 RESPIRATORY PROTECTION

Current methods of respiratory protection utilize technology that has been around since the 1950's. Today's respiratory protection devices can be grouped into the following: air purifying, supplied-air, and the self contained breathing apparatus (SCBA). Air purifying devices remove contaminants from the air mechanically (particulate filters), chemically (gas filters), or a combination of these. Supplied air devices deliver "breathable" air from a clean air source through a hose to the wearer. There are two common types of SCBA's: compressed air open-circuit and closed-circuit rebreathers. The fundamental differences between the two are discussed briefly below.

In open-circuit models, compressed air is carried in a tank and delivered to the user either on demand or in a "positive pressure" manner. The "positive pressure" ensures that any leakage will be out of the system to the atmosphere, and will not allow contaminants to leak into the system. The exhaled air in the open-circuit system is vented to the atmosphere. In closed-circuit SCBA's, exhaled

air is processed to remove carbon dioxide, then mixed with compressed oxygen for recirculation. Closed-circuit SCBA's are often referred to as "rebreathers".

Respiratory protection technologies identified during this evaluation are shown in Table 3-1 and described in the following subsections. Traditional oxygen supply technologies were not investigated because they are already well established. Advancements in this area that would benefit AIPS include decreasing storage tank size/weight and increasing their supply time. Novel oxygen storage methods and various oxygen generation technologies are described.

Table 3-1. Summary of Respiratory Protection Technologies

	TECHNOLOGY	DESCRIPTION
Not Considered[1]	Pressurization	Maintaining an overpressure within the mask.
	Automatic Valving	Assisted breathing to reduce/eliminate inhalation and exhalation resistances. Various mechanisms operate on changes in pressure, relative humidity, or temperature.
	Pressure Microsensors	Sensors used for automatic valving or pressurization.
	Vapor Scavenging	Rather than a single exhaust valve, have multiple ports around the mask.
	Conformable Bladders	Fluid filled bladders between the mask and face.
	CO_2 Absorption	Filtering exhaled CO_2 for oxygen re-use (commonly referred to as CO_2 "scrubbers").
Considered	Oxygen Storage (High Pressure or Cryogenic)	Pure oxygen is compressed to 6000 psi in special tanks, or cryogenically stored at -297°F in an insulated tank. Both utilize a rebreather system.
	Oxygen Rebreathing	A closed circuit system in which exhaled CO_2 is either removed or reacted with an agent to produce O_2 then mixed with fresh O_2 for recirculation.
	Oxygen Generation from CO_2 using Superoxides	(Exhaled) air containing CO_2 reacts with a oxygen generating agent (such as potassium superoxide).

	TECHNOLOGY	DESCRIPTION
Considered	Oxygen Generation from CO_2 using Electrolysis	Pressurized $C0_2$ is heated, passed over an electrode, and separated into oxygen.
	Oxygen Generation from Water (Vapor) Electrolysis	Solid oxide or electrochemical electrolytes are used to disassociate H_2O vapor in the atmosphere into oxygen and hydrogen.
	Oxygen Generation from Plant/Algae Growth	Plants may be used in a bioregenerative support system to generate oxygen, supply fresh food, and remove CO_2.
Impractical	Artificial Gills	Water flowing across micro-porous materials such as polypropylene hollow fibers extract dissolved oxygen from the water and dissolves excess CO_2 into the water.
	Oxygen Generation from Water Electrolysis	Oxygen is produced by electrolyzing water using and ion exchange membrane.
	Surrogate Lungs	Hollow fibers described to extract oxygen from the blood.

1 Technologies being researched under the RESPO 21 program.

3.1.1 Oxygen Storage

Description: Compressed oxygen is the primary closed oxygen source used today by those who require long term respiratory protection, such as deep-sea divers, hazardous materials handlers, and rescue workers. Oxygen is compressed to high pressures inside a storage tank, then delivered by a pressure regulator, through a hose to the individual. Cryogenic and liquid oxygen storage are processes of storing oxygen at extreme cold temperatures and very high pressures, respectively. Although oxygen storage is not a new technology, current research indicates that storage tanks of the future may be light and compact enough for integration with AIPS. Only the recent advancements in storage technologies are discussed here.

Applications: NASA has developed portable storage tanks that supply astronauts with oxygen for seven to nine hou... NASA is also currently developing a cryogenic oxygen storage unit which will store more oxygen in a smaller tank.(R1)

The high pressure storage tank occupies 0.57 cubic feet and stores three pounds of oxygen in pure gaseous form at 6000 psi. The tank is made of a nicke-chromium alloy. The oxygen is at ambient temperature and provides an astronaut seven to nine hours breathing protection. During the seven to nine hour period an over-pressure is also added to the astronauts suit for protection in the space environment, so theoretically the total oxygen available could last as long as 24 hours.

The cryogenic oxygen storage unit under development occupies 0.096 cubic feet and stores 3.2 lb of oxygen at -297°F, providing approximately the same amount of oxygen as the high pressure storage tank. Approximately one kilowatt of power may be required to bring the oxygen to its cryogenic state. The "freezing" of the oxygen could be done on a mobile cryogenic oxygen production unit which could be transported into the field. Oxygen could then be distributed to individual soldiers. Power for refrigeration would be needed to maintain the oxygen at -297°F. Proper insulation of the tank or cooling system could greatly reduce this power requirement. Dewar vessels utilizing high-vacuum insulation or evacuated powder vessels are currently available and can store cryogenic materials with losses of only 1.5% per day.[R2] One additional energy requirement is warming the oxygen to a comfortable breathing temperature.

Advantages: Present oxygen storage technologies suggest that providing 24 hours of respiratory protection is possible in the near-term. Oxygen storage technologies will require less power for operation than many of the other technologies discussed in following sections. In the case of gaseous oxygen storage, almost no electrical energy is required.

Cryogenic oxygen storage allows for large quantities of oxygen to be stored in a relatively small volume. It is also possible that the cryogenic oxygen storage system may be integrated with the cooling system of an AIPS. The cryogenic oxygen must be warmed before the wearer can inhale the oxygen. Therefore, it may be possible to pass the oxygen through the individual's suit and/or helmet to remove heat from the body while warming the oxygen to a breathable temperature. The extremely cold oxygen might also be passed over thermoelectric chips to generate electricity (thermoelectricity is discussed later in Section 3.2.4).

Limitations/Developmental Risk: The storage tank material available today are very expensive alloys. For example, a seven inch spherical tank made of inconel-718, (nickel-chromium alloy) the current material used, costs $20,000.[R1] The cryogenic oxygen would have to be transported to the

field by tanker trucks or be produced in the field using some type of mobile cryogenic factory, increasing costs and logistics requirements. The storage of oxygen at extreme low temperatures and/or high pressures presents possible hazards in handling and wear of the equipment. Additional power may be required for cooling of the cryogenic oxygen.

The weight of storage tanks will need to be reduced and the supply of oxygen increased, while maintaining safe levels of durability. Breakthroughs in lightweight, high strength material technologies are needed.

High pressure oxygen storage technology is near-term, low risk. Cryogenic oxygen respiratory technology is mid-term, medium risk. Both oxygen storage technologies may be applicable to an AIPS of the future.

3.1.2 CO_2 Absorption

Although this existing technology was not investigated during this study (as indicated in Table 3-1), a brief description is included here because some of the technologies discussed below employ carbon dioxide absorbers or "scrubbers". CO_2 scrubbers are the most common method of removing carbon dioxide from the breathing air and have been used for decades. The scrubbers are generally canisters with a granular CO_2 absorbing chemical. Scrubbers used in the past include: monoethanolamine and water (CO_2 gas is absorbed by the cool solution and ejected when heated), granular lithium hydroxide, baralyme (barium hydroxide octalhydrate, calcium hydroxide, and potassium hydroxide) , and sodasorb (sodalime). CO_2 scrubbing canisters currently used in individual systems are limited to 2-4 hours.[R3-R10]

3.1.3 Oxygen Rebreathing

Description: Rebreathers are typically closed-circuit systems in which CO_2 is removed from exhaled air and then mixed with fresh O_2 for recycled breathing. Most rebreathers utilize one of three types of oxygen sources: chemical oxygen generation (discussed later in Section 3.1.4.1), compressed oxygen, or mixed gas. Exhaled air is passed over some type of CO_2 scrubber or reacted

with an oxygen-generating agent to remove excess CO_2 and then is recycled into the breathable air. Figures D-1 through D-3 show several types of rebreathers available today.

Applications: The EX-19 Underwater Breathing Apparatus (UBA) was designed by engineers from the Institute of Diving. It consists of a lightweight backpack, full face mask, and a chest-mounted, dual breathing-bag system with pressure regulated gas addition. The UBA has a built-in microprocessor, which senses the amount of oxygen left in the closed loop system after the CO_2 reaction, then adds the required amount of make-up oxygen.[R11,R12]

Ottestad Breathing System Inc. (Norway) has developed a prototype lung powered rebreather/scrubber that uses sodalime as the scrubber material for emergency situations occurring in diving bells. Testing indicates that the scrubber should endure for at least 24 hours in an emergency situation.[R13]

A self-contained closed-circuit oxygen-generation breathing apparatus has been patented in the U.S. (4,817,597). The apparatus was tested using 400 grams of potassium superoxide as the oxygen-generating agent for a period of 30 minutes, which equates to approximately 42 pounds of agent needed for 24 hours of uninterrupted breathing.[R14]

Various SCBA's employing the rebreathing technology are described in references R6-R14.

Advantages: Recycling exhaled air back into the original oxygen source reduces waste and extends the time a fixed oxygen supply may be used. The advantage of using an oxygen-generating agent such as potassium superoxide is that additional oxygen is produced while the carbon dioxide is removed. An auxiliary CO_2 sorbent may be necessary, though, to control levels of CO_2.

Limitations/Developmental Risk: Current limitations include the amounts of oxygen, oxygen-generating material, or CO_2 removal agent that can be carried. The storage and disposal of these agents is another consideration which may need to be addressing. Also, the temperature of rebreathed, oxygen-generated air increases with time; therefore, some type of cooling must exist for rebreathing apparatus worn for a long period of time. The oxygen rebreathing technology is near-term and low-risk.

3.1.4 Oxygen Generation (OG)

Oxygen generation is the process by which O_2 is produced from one or more compounds containing a form of oxygen. Three of the processes for conversion to O_2 of specific interest include: chemical, as in potassium superoxide reacting with CO_2; electrical, in electrolysis of water vapor; and biological, as in plant/algae growth for O_2 production. Oxygen generation technologies employing these processes are discussed below.

3.1.4.1 OG from CO_2 using Superoxides

Description: Chemically produced oxygen is generated from exhaled CO_2 and moisture reacted with an oxygen-generating agent, such as potassium superoxide (KO_2) or sodium peroxide (Na_2O_2).

Applications: As mentioned in section 3.1.2 (O_2 Rebreathing), a self-contained oxygen-generation breathing apparatus has been patented in the U.S. (4,817,597) which uses potassium superoxide to react with exhaled CO_2 and moisture to produce fresh O_2.[R14] Table 3-2 lists various superoxides and their capability of producing oxygen and/or removing carbon dioxide.[R15]

Table 3-2. Summary of Potential Properties
of Some Potential Inorganic Air Revitalization Chemicals

Compound	Formula	Lbs of 0_2 Produced per lb of Compound	Lbs of $C0_2$ Scrubbed per of of Compound
Lithium Superoxide	$Li0_2$	0.61	0.56
Sodium Superoxide	$Na0_2$	0.43	0.40
Potassium Superoxide	$K0_2$	0.34	0.31
Calcium Superoxide	$Ca(0_2)_2$	0.46	0.42
Sodium Chlorate (Candles)	$NaCl0_3$	0.40	None
Lithium Perchlorate (Candles)	$LiCl0_4$	0.60	None
Hydrogen Peroxide	H_20_2	0.47	None
Lithium Peroxide	Li_20_2	0.35	0.96
Hydrogen Superoxide	H_20_4	0.73	None

Advantages: A closed-circuit breathing system in which exhaled CO_2 is replaced by fresh O_2. Only seven pounds of agent, as opposed to a forty pound O_2 storage tank, are needed for four hours of breathing protection.

Limitations/Developmental Risk: The CO_2-agent reaction is exothermic which causes the oxygen enriched gas from the oxygen-generating agent canister to be at a high temperature (up to 100°C after prolonged use). Thus, cooling of the discharged gas is necessary before human inhalation can take place. The U.S. patent mentioned above, presents a solution to reduce the inhalation temperature of the generated oxygen to approximately 40°C (after a period of 30 minutes), which is below the upper human comfort limit temperature of 52°C for gas with this moisture content. Cooling will be needed for extended use of oxygen-generating agents in a closed system.

Supply, replacement, and disposal of the oxygen-generating agent should also be considered. Research has been conducted on using superoxides since the early 60's, so a wealth of data exists on different chemicals and their characteristics. The problem has been in developing an application which is safe, reliable, and applicable to extended individual protection. Advancements in oxygen-generating agents (perhaps synthetic) are needed. Chemical oxygen-generating agent technology is near-term, low risk.

3.1.4.2 OG from CO_2 Using Electrolysis

Description: Oxygen is generated by compressing CO_2, heating it to approximately 1000°C, and then passing the gas over a zirconia electrolyte to separate the oxygen.

Applications: Oxygen generation from CO_2 electrolysis is being studied primarily for use in space applications. As a result, NASA is a major researcher in the field. Current studies are aimed at using the atmospheric CO_2 found on Mars for oxygen generation (see Figure D-4).

Current research is being conducted at the NASA Space Engineering Research Center, University of Arizona. A developmental oxygen generation plant is being studied for use in a Martian space site. Pure carbon dioxide, procured from a commercial gas vendor, is currently being used to simulate the 95.3% CO_2 atmosphere on Mars. A cylindrical, solid zirconia electrolytic cell is used to produce O_2 from the CO_2. The cell is housed within a stainless steel tube. A conductive layer of platinum is painted over the cell wall.[R16-R19]

Several zirconia electrolyte units have been developed. The first unit was twelve cubic feet, weighed 110 pounds, and generated 0.1 kg 0_2/day. The unit has operated for 900 continuous hours without failure. The second unit built was 1.5 cubic feet, weighed 40 pounds, and produced 0.1 kg of 0_2/day. A third unit is under development. It is projected that an 0_2 plant weighing between 320-430 pounds could produce 10 kg of oxygen a day.[R16]

Efforts are underway to develop a unit with a volume of 0.1-0.2 cubic feet which will weigh less than five pounds produce 0.067 kg O_2/day. Approximately 200 watts of continuous power would be needed.

Advantages: A closed-circuit breathing system in which exhaled CO_2 (or supplied CO_2) is replaced by fresh O_2. The duration of breathing protection provided would therefore be based on the capabilities of the power supplies.

Limitations/Developmental Risk: Current research is being directed towards large-scale plants for space applications, not personal-sized breathing devices. Approximately 30 of the (4 x 4 x 12) inch cells would be needed to produce 2 kg O_2/day. The Mars atmosphere in which the system is to be used is 95.3% CO_2, whereas, human exhalation will contain large quantities of nitrogen and water vapor which may affect the current electrolysis process. Also, not all of the CO_2 could be electrolyzed in the short time that it passes over the electrode, so a scrubber would be necessary to remove excess CO_2. Current developmental systems require very high temperatures and large amounts of power. Breakthroughs are needed in developing electrolytic cells that do not require so much thermal energy. This technology for personal breathing protection is mid-term, medium risk.

3.1.4.3 OG from Water Vapor Electrolysis (WVE)

Description: Water vapor in the atmosphere is passed through an electrolytic cell which disassociates the H_2O molecule into oxygen and hydrogen. The oxygen is then recycled back into the atmosphere and the hydrogen is stored for use or disposal.

Applications: In support of NASA's research of life support systems for space exploration, Life Systems Inc. Cleveland, Ohio, has developed and tested an oxygen-generating unit which uses electrolysis of H_2O vapor in the atmosphere to produce oxygen. Figure D-5 shows the WVE concept for spacecraft. The function of WVE is to generate a quantity of O_2 for metabolic consumption and

provide partial humidity control by removing water vapor from the crew atmosphere. Oxygen and hydrogen are generated from the water vapor contained in an air stream flowing through an electrochemical module consisting of a series of individual WVE electrochemical cells. Each cell consists of two electrodes separated by a matrix containing an acidic electrolyte. Specific electrochemical reactions are detailed in Figure D-6. Water vapor is drawn in to the anode side of the unit and condensed into the phosphoric acid electrolyte. Electrical energy is supplied through the cell which causes disassociation of the H_2O into O_2 and H^+ ions. The oxygen is returned from the anode compartment to the air without moisture and the H^+ ions form gaseous H_2 on the cathode side. The unit developed by Life Systems produced a one-person level of O_2 for 195 hours. The unit weighed approximately 67 pounds, occupied 1.6 cubic feet, and produced 2.5-3.0 kg O_2/day. Approximately 600 watts of power was required to operate the system.[R20]

Also in support of NASA's life support system development, Westinghouse Electric Corporation, Pittsburgh, PA fabricated and conducted performance tests of a three-man solid electrolyte CO_2 electrolysis breadboard. Testing demonstrated that CO_2 electrolysis in an oxygen reclamation system for long duration space-based habitats is feasible. Closure of the oxygen system loop (as with closed-circuit rebreathers) can be achieved by CO_2 electrolysis. In a two step process, metabolic CO_2 and H_2) vapor are electrolyzed into)$_2$, H_2, and CO. The CO can subsequently be disproportioned into carbon and CO_2 in a carbon disposition reactor and the CO_2 in turn be recycled and electrolyzed for total O_2 recovery.[R21]

A patent has been obtained on an oxygen generator and air conditioner system which consists of an electrolyzer for H_2O vapor and a chemical reactor using a solution of quick lime for removal of CO_2. Patents also exist for a solid oxide electrochemical oxygen generator which uses several electrochemical cells in series with a porous oxygen electrode and a dense solid electrolyte.

<u>Advantages</u>: H_2O vapor and CO_2 are readily available sources for oxygen production in an individual respiratory unit. Use of metabolic H_2O vapor also acts as an air-conditioning system for the environment, which would be ideal if the moisture could be drawn from inside the soldiers suit. In the case of H_2O vapor and CO_2 electrolysis, both humidity and excessive CO_2 levels are maintained at low levels while fresh O_2 is being produced. H_2 produced from electrolyzing H_2O may possibly be used for electrical power generation (fuel cells).

<u>Limitations/Developmental Risks</u>: Heat generated by the electrolysis process must be vented to the outside environment or internally cooled. Systems using only H_2O vapor electrolysis will require an auxiliary CO_2 removal agent and disposal of unused H_2, creating extra carrying and disposal

needs. Power will also be required for electrolysis. The size of the electrolysis units will need to be reduced for application within an AIPS.

WVE for AIPS is a mid-term, medium risk technology.

3.1.4.4 OG from Plant/Algae Growth

Description: Research is being conducted in which bioregenerative systems use algae to produce O_2, and in some cases, remove CO_2 from the environment. Various types of algae absorb CO_2 and sunlight, thus producing biomass and O_2. Experimentation with growing certain strains of algae in an inert atmosphere have produced slightly different effects. Some types of algae will also split water into H_2 and O_2 when grown in an inert atmosphere.(R22-R26)

Applications: The majority of applications are developmental items in support of NASA's Closed Ecological Life Support System (CELSS). Researchers have developed and implemented a photobioreactor system to produce oxygen. Highlights of the system include an optical, internal, light transmission system, gravity-independent gas-exchange, and an ultrafiltration unit. The fiber-optic based optical transmission system illuminates the reactor internally and includes a light source which is external to the reactor, preventing heat generation problems. The prototype, using Chlorella vulgaris as the media, was operated for two months in batch and continuous modes. Oxygen was produced at a rate of 4-6 mole/L of the culture per hour under continuous operation.(R22)

A cultivation system has been developed by Japanese researchers for continuous production of algae in a closed condition. Spirulina oscillatoria and Spirulina subsalsa are used in a liquid culture medium for food production and gas exchange (oxygen being a product) in a CELSS. Tests were done to demonstrate the system operating at various temperatures, pressures, and light conditions. No technical O_2 production data was presented.(R23)

Researchers at the Oak Ridge National Laboratory, Oakridge, TN are experimenting with growing Chlamydomonas in an inert atmosphere of nitrogen, argon, and helium for conversion of biomass into fuels. When grown in an inert atmosphere, the Chlamydomonas divert their photosynthetic energy to split water into O_2 and H_2.(R24)

Advantages: Various algae remove CO_2 and H_2O from the atmosphere while producing O_2 in return. Many algae exhibit properties of rapid growth, high utilization of CO_2, and survival in varying conditions. Algae processes are regenerative, thereby increasing the possibilities of long-duration oxygen supply from a single source.

Limitations/Developmental Risk: Most of the research being conducted is for large scale applications in space situations, so downsizing the process would be necessary for AIPS. Increasing amounts of biomass, which must be disposed of, are created during the biogenerative process. Hydrogen is another product which must be utilized or disposed of. A light source will be needed by most algae for growth to occur. Researchers have not been able to "engineer" specific types of algae easily, if at all, although advances in bioengineering of plants would assist the development of this technology. The technology of using algae for O_2 production for APIS is far-term and medium risk.

3.1.5 Impractical Respiratory Protection Technologies

Artificial Gills

Artificial gills are materials made of micro-porous fibers which extract dissolved O_2 from water when water flows over them.[R27-R29] Experiments have determined that animals, and even resting humans can be kept alive, but with massive quantities of water needed. Figure D-8 shows two artificial gills and test data for hamster breathing. The technology works, but water must be continuously pumped over the gills to maintain proper O_2 levels, making the technology inapplicable to an individual protective system.

OG from Water using Electrolysis

Electrolysis of water is being studied as a method of producing oxygen in a submarine or space habitat. Figure D-9 is a schematic of the water electrolysis process. Like water vapor electrolysis (discussed previously in Section 3.1.4.3), the technology is effective for producing O_2. The feasibility of using the electrolysis process at sea for replacement of oxygen storage has been researched.[R30-R31] Electrolysis of water is not practical for individual respiratory protection because of the need for a water supply source which would have to be carried by the individual soldier. However, the fundamentals demonstrated in water electrolysis are similar to those for water vapor electrolysis. Advancements in this technology could benefit WVE.

Surrogate Lungs

Surrogate lungs, sometimes called "membrane oxygenators", are microporous hollow fiber materials which extract oxygen from blood.[R32] Blood passes around the network of hollow fibers and oxygen in the blood diffuses into the hollow fibers where it can be delivered. Applications are being developed for the medical field, primarily for surficial support. The technology parallels the artificial gill technology for extraction of oxygen from water, but blood is the supply of oxygen in surrogate lung technology. Thus, surrogate lungs are not a viable research option for an AIPS.

3.2 THERMAL MANAGEMENT

The battlefield of the future will introduce multiple unknown threats. If advancements in semi-permeable protective clothing can't overcome these threats, protection for the individual soldier will be provided by some type of impermeable, totally encapsulated system. In order for a soldier in protective gear to perform mission operations in extreme environments, microenvironment conditioning will be needed to assist in thermoregulating the human body. Personal heating and cooling devices are readily available. Examples are "electric" socks and cooling vests. However, these items are too bulky for a combat soldier or require amounts of power that cannot be supplied to the soldier.

Thermal management technologies identified during the evaluation are shown in Table 3-3. Most of the technologies investigated prior to this evaluation are limited to personal cooling. In the past, cooling has been more critical than heating, due to high levels of heat stress imposed on individuals wearing protective clothing. The most common form of personal cooling is microclimate cooling (MCC), which in general was not investigated in this evaluation as to prevent duplication of NRDEC's research efforts described in the MCC master plan[T1]. However, MCC applications are discussed briefly because several technologies described here would employ MCC principles.

Truly "novel" thermal management technologies were not identified during this evaluation. Technologies considered applicable to an AIPS have already been developed, but not yet fully integrated with an individual cooling system: phase change materials, heat pipes, and thermoelectricity. All these technologies could provide a means for transporting heat (or cold) away from the human body.

There are general criteria for temperature control in near-contact with the body. The method of cooling (or heating) must be flexible, nontoxic in the event of accidental contact, and maintain safe levels of heat transfer. Typical skin surface temperature is about 85°F (29°C). In the presence of very heat-conductive media (such as water), it is hazardous to risk exposure to the skin at temperatures over 108°F (42°C). Conversely, localized cooling below 45°F (7°C) may cause discomfort, as in the case with the gel packs used for sports injury therapy.[T2]

Table 3-3. Summary of Microenvironmental Conditioning Technologies

	TECHNOLOGY	DESCRIPTION
Not Considered	Heat/Moisture Absorbers[1]	Monofilament fibers that move heat/sweat away from the wearer via a "wicking" effect.
	Multipurpose Laminates[1]	Microporous membranes that have high moisture vapor transmission rates, yet still provide environmental protection.
	Environmental Microsensors[1]	Miniature thermocouples, thermostats, and pressure sensors for monitoring environmental conditions.
	Microclimate Cooling (MCC)[2]	Removal of heat from the body by circulating an ambient or conditioned fluid through an article of clothing worn close to the wearer's skin.
	Sonic Refrigeration[2]	Acoustic waves used to compress refrigerants.
Considered	Phase Change Materials	Materials that use latent heat of fusion for thermal management.
	Heat Pipes	Material that use latent heat of vaporization for thermal management.
	Thermoelectricity	Heating, cooling, or power generation from materials with thermoelectric properties.

1 Technologies being researched under the RESPO 21 program.
2 Technologies being researched under the SIPE program.

3.2.1 Microclimate Cooling (MCC)

MCC provides the mechanical removal of heat from a soldier in a protective ensemble. An MCC Front End Analysis (FEA) was performed under the direction of the U.S. Army that evaluated several cooling methods, including ambient air, conditioned air, conditioned liquid, and iced-based MCC units. These methods of cooling and some of their applications are discussed below. Major drawbacks of these systems include weight and volume of the units, portability, power, and limited duration of operation.

3.2.1.1 Ambient Air MCC

An air cycle MCC backpack is under development at NRDEC, which uses ambient air as the working fluid in a personal-sized heat pump. The design employs a high-speed centrifugal compressor, expander, and heat exchanger in a backpack configuration. The major obstacle in such a system is the weight of the compressor and the motor which drives it. NRDEC's Soldier Integrated Protection Ensemble (SIPE) program is demonstrating the use of an ambient air MCC unit.

3.2.1.2 Conditioned Air MCC

The conditioned air MCC unit uses pre-conditioned air rather than ambient air as the working fluid. An example is the air cooling system used by combat vehicle crew (CVC) personnel, which consists of a vehicles air conditioning (AC) system connected to air distribution vests via flexible tubing. The AC system uses a vapor compression unit with R-12 refrigerant, and is housed within the crew compartment, as opposed to being carried by the individual. The vests have two air distribution manifolds, one on the chest and another on the back.

3.2.1.3 Conditioned Liquid MCC

Conditioned liquid MCC units use a setup similar to the air MCCs with the exception that a liquid (e.g. water and glycol mixture) is used as the working fluid. A liquid cooler (vapor compression/R-12 unit) is used to condition the working fluid, which is then recirculated through a close-fitting torso vest containing lengths of plastic tubing.[T3] The advantages may include increased efficiency and increased cooling capacity over conditioned air MCC systems.[T4]

The Self-Contained Toxicological Environmental Protective Outfit (STEPO) uses a liquid cooling system, as does the Individual Microclimate Cooling System (IMCS).

3.2.1.4 Ice-Based MCC

Ice-based MCCs use pre-frozen ice instead of mechanical means as the cooling medium. The working fluid (typically water) is recirculated through a reservoir of ice, where it is chilled then pumped through a cooling vest. The ice reservoirs have a limited service time before they must be

recharged, depending on reservoir size. Icewater vests worn by Canadian helicopter pilots in the Persian Gulf provided up to one hour of cooling, using an 8.5 lb. cooling unit. The vest consists of tubing sewn in the fabric at 1.0 inch intervals to carry the ice-cooled water. A cooling shirt constructed in a similar way is shown in Figure D-10.(T5)

The TAP (Toxicological Agent Protective) suit Cooling System (TCS) uses a commercial, active ice-based system. The vest is worn under the suit and the cooling unit is worn on the back.

3.2.2 Phase Change Materials (PCMs)

Description: Phase change materials (PCM's) use the latent heat of fusion (heat energy needed to change a material in solid state to liquid state at a constant temperature) to remove heat from a microenvironment. For example, paraffin wax is a straight chain crystalline hydrocarbon that can be placed in a cross-linked polyethylene matrix. This form of PCM freezes and melts in the 15-40°C range, releasing heat into a cool environment as it freezes and drawing heat from a hot environment as it melts.(T6,T7) The high latent heat of fusion associated with a PCM requires a lot of energy to melt the material, thus making it an excellent heat sink. Conceptual heat storage modules that employ PCM's are shown in Figure D-11.

Applications: Commercial products that demonstrate fundamentals of the PCM technology include the frozen "gel-packs" used for sports injuries and frozen "ice blocks" used in picnic coolers. Potential industrial uses for PCM's include heating and cooling of buildings, thermal protective wraps, cooling electronics, coatings, or food refrigeration. PCM's encapsulated in microbeads (microPCM's) have been woven into developmental thermal storage clothing (gloves, vests, and undergarments).(T8)

Concordia University in Montreal has worked with PCM's based on fatty acids and fatty acid esters; these have the following advantages: renewable resources, obtained from vegetable and meat by-products, and variable phase-change properties.

Battelle has developed concepts for alternative materials for therapeutic treatment of sports injuries. Generally, these materials may be classified into organic PCM's and special gel materials. Organic PCM's include: N-Alkanes (straight chain paraffins), polyethylene glycols, and salt hydrates and fused salts (inorganic materials). The N-alkanes and polyethylene glycols exhibit melting temperatures ranging from 21-28°C, and have heat from fusion ranging from 30-60 cal/g. Several

sodium, potassium, and calcium based salts are commercially available and have the potential to meet the required phase-change properties. In addition, these materials are generally compatible with most plastic materials and exhibit low toxicity.

Special gelled PCM's have a limited history, but Dow Chemical Company has developed a method for gelling salt solutions, including a stabilizing additive. Also, Battelle scientists have worked with a class of amino acid derivatives for gelatinizing various fats and oils. A thermally reversible gel material can be formed from a magnesium salt of an alternating butadiene, maleic anhydrate copolymer; this material has a reverse phase change behavior, that is, it becomes a liquid when cooled, and a solid when warmed. Other materials, classed as biopolymers, which exhibit this same behavior are collagen, ovalbumin, soybean protein, and various forms of elastin.[T9]

Other natural and synthetic polymers, normally used as thickening agents and chemical modifiers, could be explored for use with phase change systems. Some of these materials are: polyacrylamide, xanthan gum, emulsan (an emulsifying agent), gelatin, hyaluronic acid and agarose. Alternately, a whole family of inorganic materials can be formed into gels and colloids which exhibit unique physical, electrical and chemical properties.[T10-T12]

For AIPS, PCM's could be used in cooling electronics, conditioning air in the respiratory system, or conditioning the entire microenvironment.

Advantages: After a PCM "unit" has completely changed phase, it can be recharged and used again. Recharging can be done with ambient cooling, cold water purifying, refrigeration, or the injection of compressed CO_2 from a small cylinder, depending on the physical properties of the PCM. Combinations of PCM's can provide thermal control over a broad range of temperatures. The advantages of paraffin waxes (crystalline alkyl hydrocarbons) are that they are readily available, they are a low cost byproduct of petroleum refining, and can be blended to have melt-transition zones over a range of temperatures estimated between 15-40°C.

PCM's can be used for both active and passive heating/cooling. Active cooling with PCM's is similar to liquid-based MCC except the working fluid would be a liquid slurry containing PCM's, instead of water. Passive cooling with PCM's uses heat storage rather than heat removal for cooling. Testing of a PCM liquid cooled garment demonstrated a significant improvement in thermal control of the human body over standard water cooled garments. These same studies also indicate that fluid thermal capacitances can be made to exceed 50 times (5000%) that of water, while the heat transfer coefficient can be significantly enhanced by over 100%.[T8]

If passive PCM's are used, no power is needed for cooling/heating, which is a definite improvement over standard MCC units. A microencapsulated approach isolates materials and prevents direct bodily contact with the PCM. However, encapsulation constrains PCM during the melt phase, thus reducing its overall efficiency.

Limitations/Developmental Risk: Current limitations of PCM's include energy storage capacity (directly affects time of operation), maintaining the PCM in its "ready" state, and recharging for reuse. These parameters are all affected by conditions in the operating environment. Data we acquired during the evaluation did not indicate time durations of cooling/heating for PCM's, simply because of the variables involved: operating temperature range, cooling/heating needs, PCM properties, and method of employment. PCM's are a near-term, medium risk technology.

3.2.3 Heat Pipes

Description: Heat pipes use the latent heat of vaporization (heat energy required to change a material in liquid state at a constant temperature). In a heat pipe, a small quantity of working liquid is placed in a tube (or other such container), air is evacuated from the tube, and the tube is sealed. Heat is applied to one end, which causes some of the liquid to vaporize. The vapor moves, due to its higher pressure, to the other end of the tube where it is condensed. The liquid condensate then returns to the heated end by a wick fixed to the inside wall of the tube, wherein capillary force returns the condensate to the evaporation section (gravity or small pumps can also be used to accomplish this). An example of a gravity assisted thermosyphon is shown in Figure D-12. For a working fluid with a high latent heat of vaporization, high heat transfer rates can be achieved with small temperature difference between hot and cold ends of the tube.[T13]

Heat pipe technology has existed for a long time, but new working fluids and micro-tube manufacturing technology has renewed research interest. Axially grooved heat pipes have been manufactured to increase operating efficiency of the working fluid, which in turn increases system efficiency.

Applications: Heat pipes are used for both heating and cooling. Heat pipes are often used to remove heat from electronics modules, machine bearings, and equipment that doesn't allow conventional air cooling.[T14] In the space industry, heat pipes are used to control the temperature of shuttle payloads, communications satellites, and instrumentation modules.[T15]

An innovative application has been developed that uses heat pipes for warming the hands in cold environments. Thermal energy from the elbow vaporizes the working fluid, then it is transferred to the fingers via heat pipes, where heat is given off during condensation. The hands are a natural radiator, due to the dense population of blood vessels near the surface, and the comparatively small cross-sectional area at that location; a similar situation exists for the feet. In the opposite situation, where cooling is required, it will be necessary to improve the radiating capacity of the hands and feet. Various concepts of the heating glove are shown in Figure D-13.[T13]

For AIPS, heat pipes could be used to cool equipment, remove heat from the head, and/or manage heat throughout a totally encapsulated suit.

Advantages: Heat pipes offer very high heat conductivity, fast response, low maintenance, and flexibility. Depending on how heat pipes are employed, power may not be needed for cooling or heating.

Limitations/Developmental Risk: Shortcomings of heat pipe use for AIPS are selecting a working fluid for human applications and optimizing a system design. Further investigations into working fluids that can operate at 10-15°C will be needed. The heat pipe glove mentioned above uses freon as the working fluid, which may not be practical for complete garment cooling/heating. However, as environmentally safe, synthetic refrigerants are being developed in industry, new working fluids for heat pipes will be made available. Heat piping for AIPS is a near to mid-term, low risk technology.

3.2.4 Thermoelectricity

Description: Thermoelectricity is the production of thermal energy from electricity, or vice versa. There are two fundamental thermoelectric effects of interest that have been known since the 19th century: the Seebeck effect and the Peltier effect. Seebeck demonstrated that an electric current could be produced in a closed circuit composed of two different conductors if one junction of the dissimilar materials was maintained at a temperature different from that of the other junction. Peltier observed that heat was either absorbed or desorbed at the junction of two dissimilar materials when an electric current was passed through the junction. The principles of the two effects are listed below and shown in Figure D-14.

Seebeck: thermal energy input = electrical current output

Peltier: electrical current input = thermal energy output

The thermal energy can be heating or cooling, and is dependent on the orientation of the materials, with respect to the hot and cold junctions.[T16]

Applications: Thermoelectric materials can be used for cooling, heating, and generating electricity.[T17] Thermoelectric technology has a wide range of current application in military and aerospace systems, manufacturing processes, laboratory and scientific equipment, consumer products and medical instrumentation. Specific applications include use in a space-borne air-conditioning unit, a military signature reduction shield, air pollution control analyzers, a cold/hot medical therapy pad system, and even beer keg coolers.

Electro-optics applications include temperature regulation of solid state lasers, infrared detectors and charge-coupled devices (CCD's) in electronic equipment such as high resolution CCD cameras and thermal weapon sights. Volumetric cooling of small volumes of air or liquid and cold plates has applications in environmental chambers and small forced-air cooling systems.

A solid state air conditioner using thermoelectric principles has current application in motor vehicles and control instrument cooling. It requires no compressor and weighs 3.4 kg (7.5 lb). The unit has a rating of 240 BTU/HR, operates on input voltage of 12/24/48 VDC, and in a temperature range of -30°C to +60°C. A slightly larger model, weighing 5.4 kg (12 lb), has optional heating capabilities of 340 BTU/HR. As the technology continues to be developed and more efficient materials are utilized, smaller models with AIPS applications may emerge.

Using materials available today, thermoelectric refrigerators suitable for use in homes are more expensive and less efficient than standard vapor compression-cycle refrigerators. Thus their use is largely restricted to situations in which lower maintenance, increased life, or quiet performance are essential, or in situations (such as in space vehicles or satellites) in which compressor-type cooling is impractical. A number of small refrigerators are in use in hotels. A typical unit having about a 50 liter capacity requires a dc power input of 40 W and a refrigerative capacity of 23 W. Small cooling units with capacities of 10 W or less have been developed for cooling small electronic equipment such as integrated circuit boards.[T18]

A thermoelectric heater is nothing more than a thermoelectric refrigerator with the current reversed. A commercial device that demonstrates this concept is the baby bottle cooler-warmer, which cools the bottle until just before feeding then switches to a heating cycle to warm it.

A thermoelectric generator requires a heat source and a thermocouple. Kerosine lamps and firewood have been used as heat sources in producing a few watts of electricity in locations where electricity was otherwise unavailable. A thermoelectric generator has been developed for vehicles or

boats operating in cold climates. The prototype uses diesel powered heater (11,000 BTU/H) as the heat source and the surrounding environment as the cold source.[T19]

Perhaps the most prevalent application is cooling with thermoelectric chips, which are shown in Figure D-15. These chips have a variety of applications similar to those mentioned above. Typically, chips are used for localized cooling, where small areas or individual machine/electronic components require large amounts of cooling, that can be attained from conventional methods of cooling. A good example is cooling high speed integrated circuits.

Thermoelectricity could be employed in a variety of ways in an AIPS. If enough power is available, heating or cooling could be accomplished through a series of small thermoelectric chips sewn together in a garment. The body (or electronics in AIPS) could be used as a heat source and ambient air as a cold source for generation of small quantities of electricity, which in turn could be used to power a small blower for air circulation within a protective ensemble.

Other application possibilities include temperature control of the AIPS respiratory system, as well as the helmet; an air-conditioned motorcycle helmet has already been developed by TE Technology.[T20] AIPS' computer and electronics will also require cooling. Boots, gloves, and water bottles could all be temperature-regulated by thermoelectric technology.

Advantages: The thermoelectric systems mentioned above require low maintenance, are long lasting, and have no acoustical or electrical noise signatures. They can also operate in either cooling or heating modes, depending on current direction. Thermoelectric modules operate in any orientation (horizontal, vertical, etc.), and have high resistance to shock and vibration. They require no moving parts, compressor or piping, and they eliminate the need for gases or fluids. Thermoelectric technologies provide precise temperature control to less than 0.5 °C, as well as continuous cooling or heating with no recharging. The modules are small, lightweight, and typically powered by a DC source.

Limitations/Developmental Risk: Power would be required for heating or cooling applications. The amount thermoelectric energy that can be converted depends on the temperature difference between hot and cold sources. Potential AIPS applications would involve low temperature differences. Most thermocouple materials operate effectively at high temperature differences. The development of thermoelectric materials with higher figures of merit is needed to increase the efficiency of today's thermoelectric systems. Producers of thermoelectric systems are funding research to develop more efficient materials. Thermoelectricity for AIPS is mid-term, medium risk technology.

3.3 VISION/OPTICS

AIPS vision/optics technology seeks to meet two requirements of the soldier. First, the system needs to protect the soldier's eyes from direct energy, such as blinding lasers. Second, to enhance the soldier's effectiveness by visually providing him/her with critical information needed to execute a m' sion.

Some vision enhancement technologies are already commercially available. Heads up displays are now used in military aircraft, and night vision systems are available both for aircraft pilots and for ground troops. These systems are nearest to a realization for improvement and/or adaptation for use in an AIPS. Other optical display devices such as scanning mirrors are currently available in the consumer market and could be employed by an AIPS. Technologies used by manufacturers and designers, such as 3-D imaging and geometric reasoning offer potential AIPS applications.

Fewer vision protection options are currently available due to limitations in computer capabilities. Current computer and sensor technology cannot perform the arduous task of converting incoming analog images to digital format, filtering out harmful elements, and then re-converting back to an analog image fast enough for real-time human vision. Technologies such as neural networks (discussed later in section 3.5.2) and intelligent photo sensors (discussed in section 3.3.4) are now being developed and will make real-time vision enhancement and protection possible in the future.

Table 3-4. Summary of Vision/Optics Technologies

	TECHNOLOGY	DESCRIPTION
Not Considered	Multipurpose Coatings[1]	Polycarbonate materials for totally transparent masks.
	Fresnel Lenses[1]	Optical enhancements via asymmetrical lens configurations (e.g. automobile "tail-lights").
	Thermal Imaging/ Infrared Imaging[2]	Image intensification via heat radiated from object.
Considered	Image Intensifier Tubes	Image intensification used for night vision goggles.
	Heads-up Displays	Image projected (or created) on a glass plate, windshield, or visor.
	Scanning Mirrors	Image formed off of vibrating mirror.
	Intelligent Photosensors	Photosensors embedded in computer circuits for image processing.
	3-D Imaging	3-D images formed from standard image sources.
	Image Enhancement/ Compression	Computer improvement of images and reduction of image computer storage requirements.
	Geometric Reasoning	Method of computer object recognition.
	Virtual Reality	Complete immersion in a computer-generated environment.

1 Technologies being researched under the RESPO 21 program.
2 Technologies being researched under the SIPE program.

3.3.1 Image Intensifier Tubes

Description: Image intensifier tubes are employed by night vision goggles (NVG's). The wearer of the NVG can see monochrome, multishade images of the surroundings when in semi-darkness through the amplification of small amounts of light, such as moonlight or starlight. The tubes function by converting photon rays generated by objects into a visual image for enhanced night vision. Before entering the image intensifier, photons pass through a series of lenses and filters. The viewer then observes the output of the image intensifiers in one of two ways. With some

NVG's, the viewer looks directly at the output ends of the image intensifier tubes (one for each eye), while in others the image arrives to the viewer in an indirect manner in the form of a reflected projection placed in front of the eye. A comparison of vision through unaided eyes, image intensification tubes, and infra-red devices in illustrated in Figure D-16.

There have been three "generations"of intensifier tubes, each improving on the previous design. The current tube in use is the third generation, and is much smaller and offers a superior image compared to its predecessors. Within each tube are three elements: a photocathode that converts photons to electrons, a microchannel plate to amplify the electronic signal from the photocathode, and a phosphor screen to convert electrons back to visible light (see Figure D-17).[V1,V2]

Applications: Night vision goggles (NVGs) for pilots, combat vehicle crewmen, and special ground surveillance personnel employ the image intensifier technology. The aviators night vision imaging system (ANVIS) uses the third generation image intensifier tubes with a high resolution phosphor screen (36-40 line pairs per millimeter). In comparison, a typical 19 inch television set, which also uses a phosphor screen, has about 1.7 lines, and a high-definition television has about 4.4 lines. The "Eagle Eye" low profile NVG system integrates the third generation image intensifier tubes with a lightweight, helmet compatible night vision system.[V3] Concept diagrams of developmental night vision systems are shown in Figures D-18A and D-18B. The image intensification tubes used with these systems could be easily integrated into AIPS' vision system.

Advantages: Recent advancements in intensifier tube manufacturing has significantly reduced their size which resulted in lightweight goggle systems with minimal center of gravity shift. Other improvements include a wide, see-through field of view (160° x 110°) available when the NVG is turned off. In the future, ongoing research and development will introduce even smaller tubes with larger fields of view.

Limitations/Developmental Risk: The field of view of the intensified image is significantly reduced compared to unimpaired vision: the NVG image is 40 degrees circular, unimpaired human vision is approximately 90 degrees horizontally and 60 degrees vertically. The third generation image intensifier tube technology is fairly well established. The only shortfalls come with integrating the tubes with a vision system. Improvements are currently being made for flash protection, life support equipment integration, and general performance improvements for a variety of applications. Image intensifier tubes for an AIPS are near-term and low risk.

3.3.2 Heads-up Displays

Description: Helmet mounted displays (HMD's), a type of heads up display (HUDs), are used to rapidly provide a user with important information, without interrupting the user's operations, via a visual display. The display consists of information either projected or created on a viewing surface. Images can be projected onto a helmet visor and reflected into the soldier's eyes, or created on a cathode ray tube (CRT) or liquid crystal display (LCD) screen.

Applications: Heads-up displays are useful in any application where a person needs to receive information while looking forward. In an aircraft, for instance, the pilot needs to observe both the scene through the windshield and gauges located separately on cockpit console. HUDs project a CRT image upon the windshield or a plate of glass in front of the viewer's eyes, so that the operator can simultaneously view the conditions outside and important information regarding the operation of the aircraft (see Figure D-19).[V4] Until recently such systems were found in military aircraft only, but now HUD systems are being designed and offered for commercial aircraft. HUD's have also solved the problem helicopter pilots have when wearing NVG equipment and reading cockpit gauges. Previously, pilots reported difficulty reading these gauges because of the comparatively high brightness of the gauges compared to the darkness outside. Kaiser Electronics has developed an HMD to eliminate this problem by displaying necessary information on the pilot's visor.[V5]

Similarly, a HUD system could be useful in a protective helmet by superimposing data, such as messages from the base, NVG battery status, directional compass, etc. upon the helmet's visor or the NVG screen. One particularly interesting application projects thermal imagery data onto the visor of Navy firefighters operating in smoke filled spaces.[V6] The SIPE program is demonstrating fundamentals of the HUD/HMD technology for an individual soldier's vision system.

As LCD technology matures, displays projected onto the visor may be replaced by images created on a LCD computer screen placed in front of the eyes. State-of-the-art LCD technology is currently being demonstrated by active-matrix thin film transistor (TFT) color screens for lap-top personal computers and miniature televisions.

Advantages: Quicker display of information (for AIPS: data on enemy target, status of protective system, location of friend/foes, etc.), enables display of information when no space is available for gauges and other readouts (such as inside a helmet).

Limitations/Developmental Risk: Current drawbacks to HUDs include interrupted field of view, fragility, data processing equipment, power for operation, and depth perception. As video display and computer processing technologies advance, these potential problems will be overcome. Heads-up displays are a near-term, low risk technology.

3.3.3 Scanning Mirrors

Description: Scanning mirror technology (also called vibrating mirrors) is an innovative way of creating a virtual image, which does not use a CRT or LCD matrix. Instead, it simulates a 12 inch video screen image using a 1 inch eyepiece by placing it close to the user's eye, and creates an image by reflecting a vertical column of LED's off an oscillating mirror. Currently, such a device is available to the consumer called the Private Eye™; a starter kit is available from Refection Technology for $495 (see Figures D-20 and D-21).[V7-V9]

Applications: Scanning mirror display devices could be useful as an auxiliary display device to provide a soldier with helpful information, such as mission instructions, a map of the environment, or schematics for equipment repair. The device might be mounted toward the top of the helmet, so that it would not interfere with normal vision and could be glanced at by the soldier when needed. Future systems will present an entire screen for both eyes, and could coordinate these screens to create a three dimensional, stereo image. Scanning mirrors could also become an alternative to CRT's or LCD's for projecting heads-up display data, in which it could project a computer image to a visor or face shield, rather than a one inch screen.

Advantages: The advantages of such a system are its compact size, low weight, durability due to simple design, low power requirements and image processing speed. This small, lightweight computer screen does not require hand operation and can be very useful in providing information to the soldier. For example, the private eye weighs only 2.5 ounces, requires 0.01 watts, and can create an image of 280x750 (10 million) pixels per second.[V7]

Limitations/Developmental Risk: The current device completely blocks one eye when in viewing position, thus users need to adapt to working with one eye. Alternatively, this device could be mounted in a position where it would not interfere with normal vision, but could be glanced at. As with HUD's, depth perception could be a potential problem for AIPS. Scanning mirrors are a near-term, low risk technology.

3.3.4 Intelligent Photosensors

Description: Photosensors are devices which detect light. Intelligent photosensors consist of a silicon board holding processing hardware and a built-in array of photosensors, which can identify objects and track motion (see Figure D-22). These devices use technology developed through studies on how the eyes, ears and brain function and can process much larger amounts of incoming data than traditional photosensor systems. One reason for this increase in speed is that unlike typical photosensor arrays, intelligent photosensors do not need to pass data from each photosensor through an analog to digital converter. Instead, intelligent photosensor arrays perform the processing of data at the analog level allowing increased processing speeds. Future sensors may be able to scan various wavelengths of the electromagnetic spectrum and form realistic images from the "sensory" details obtained at different wavelengths. The computing portion of the sensors will be analog neuroprocessors (ANP's) employing advanced VLSI (very large scale integration) circuitry capable of continuous, real time processing of the data.[V10-V16]

An integrated circuit model of the human retina is being developed at Synaptics, Inc., San Jose, CA. The circuit consists of an array of photodetectors wired together in such a way that when light falls on the chip, it is instantly processed to detect motion (see Figure D-23). In present day imaging systems, sequential electronic "snapshots" of a scene must be transmitted to a computer, which then compares successive frames to extract movement information. Not only is this process data intensive, it requires complex digital algorithms.

Applications: Unlike an ordinary camera, these devices can describe the images they receive in detail, rather than simply photographing them. These sensors are an ideal choice for input devices for image processing devices, geometric reasoning systems, or image enhancers. The sensor array could use its built-in capability to pre-process the incoming images to reduce the load on the image processing computer. Another use would be to employ a sensor array on a helmet through a fisheye lens to detect motion in all directions. The sensor would detect motion in regions the soldier is unable to see and alert him.

Advantages: Because the sensor and microprocessor are integrated in one unit, the device would be inexpensive and can be easily mass produced. They are extremely rugged and are suitable for harsh environments. These sensors do computations in a parallel, analog method which makes them extremely fast. Using ANP's in future designs may allow a single analog chip to yield the equivalent processing power of a digital supercomputer.[V10]

Limitations/Developmental Risk: Advances in material technology are needed to assist advancement of intelligent sensor designs. Research on photo-chemical and electro-chemical materials that best simulate neuron activity is being conducted at MIT. Advances in data processing equipment, such as miniaturization and reduction in power needs, will be needed in order for AIPS to have the capability of using intelligent sensors. Figure D-24 demonstrates the complexity of an integrated sensor and analog processor for visual images, in which the neural optics of a mammalian retina are simulated with electronic circuitry. Intelligent photosensors are a mid-term, high risk technology, due to their dependency on computing power.

3.3.5 Image Enhancement/Compression

Description: These techniques involve image processing of the source image by a computer to enhance or compress it. When enhancing an image, a computer 'looks' at a captured image and modifies it to increase clarity, and to reduce distortion. Enhancement is useful in any circumstance where either the source image is vague or when the transition through the camera to the viewer creates distortion or other losses. In the second mode, the computer compresses an image by carefully removing information not required to maintain the original appearance within a specified tolerance.

Applications: Currently image enhancement techniques are used by police departments to identify license plates, people, and other items which cannot be clearly seen in photographs or videotapes. In one demonstration of this technique, a license plate of an escaping car was deciphered. In the original photograph, the license plate was completely unreadable. The computer then applied the enhancing techniques to remove noise and enhances vague areas, resulting in a clearly readable license plate. Such techniques are also used by the military to improve the quality of satellite surveillance photographs. Unfortunately, because the computing power required to perform this processing is so high, current image enhancement techniques can only be applied to still images.

In the future, image enhancing techniques could be employed in both real time vision and single frame systems. Although current computers cannot process images fast enough to provide a real-time enhancement of each image, such capability will be available as algorithms and computer hardware improve. When such advances are achieved, image enhancement could be used to improve the quality of a night vision system. The NVG would receive the source image, send it through the image enhancing unit, and an enhanced image would arrive to the viewer. During the enhancement

process, the computer can improve the image in several ways. It can determine which areas of the image are too dark, and automatically adjust the contrast to compensate. Distortion can be removed by taking two pictures one right after the other, and removing parts not found in both images. One real-time image enhancement system now under development is called 'Sensor Fusion'. This technique allows the combination of data from several sensors to electronically produce an enhanced image for the pilot.[V6]

Currently available single frame image enhancing systems could be used by soldiers in surveillance missions. For instance, a soldier might be secretly observing an enemy installation, and needs to identify military vehicles, hostages, key personnel, etc. A complete system contained in his helmet could capture a photograph, zoom in on an area of interest, and then enhance the image to help the soldier determine what is located on the base. Currently, to do the same operation, the soldier needs to bring a camera, take the picture, then take the film back to the base to be developed, digitized, and processed, requiring more time and effort.

Compression techniques could be used when it is desired to store, transmit, or apply further processing to the image. In the above example, a soldier could compress the processed photo, and then send it to another soldier's helmet for immediate display, or back to his headquarters for review by the commander. The compressed image would take less time to transmit, allowing more images to be transmitted over the same period of time compared with uncompressed images. Advanced compression techniques are already in use, including protocols available for personal computers to compress computer image files. A user tells the program the tolerance he desires between the original image and the compressed image, and the computer creates a new, more compact image file.

Advantages: Improved image available to the user, reduced image transmission time, and reduced computer processing requirements due to smaller image size.

Limitations/Developmental Risk: Current image enhancing and compression systems are not fast enough to cope with a data stream of a sequence of real time images; therefore real-time image enhancement is a long-term, medium risk technology. Current NVG systems do not allow the image to go through a processing computer first, but new, highly compact systems like the Eagle Eye NVG have an intermediate stage between the source image and the eyepiece where such a processor could be implemented. Use of enhancing and compression systems for still frame processing is currently possible with desktop size computers, making it a near term, low risk technology.

3.3.6 3-D Imaging

Description: Two dimensional images are very simple to create because they require only one camera source and there is only one image which needs to be presented to the viewer. Three dimensional images are more difficult to create because they require two camera sources to achieve the parallax viewing that human eyes utilize to perceive depth, and because the two images need to be aligned when presented to the viewer or the 3-D effect will not work. 3-D imaging techniques create or simulate three dimensional viewing conditions to provide the viewer with more depth perception cues.

Applications: Currently, soldiers wearing masks, NVG equipment, or flight helmets retain their binocular vision and do not need 3-D imaging assistance. In masks and helmets, the soldier simply looks out through a clear shield, and in current NVG systems there is a separate intensifying tube for each eye. There may be situations, however, when it would be desirable for the soldier to relay stereo images back to a base for review, or so that a commander could 'look through the eyes' of the soldier. Currently the VISIDEP system is the leading method to re-create 3-D images on a single CRT. VISIDEP is used in conjunction with either stereo LCD shutter glasses, or with a special processing technique called "Alternating Frame Technology" (see Figure D-25). [V17]

The alternating frame method is unique in that it requires no shutter glasses or other special viewing equipment to observe a 3-D image on a single CRT screen. This technique can also work using either two or one camera(s) to capture the source image, although the one camera source is limited to applications such as airplane surveillance where the camera travels in a smooth, straight line.

A 3-D digitizing system which uses a video camera, laser, and personal computer to create digitized images of real-world objects is currently on the market. It is presently used in the automotive and aerospace industries in Europe and is capable of creating a CAD drawing from a physical prototype. The size of this system currently restricts its application to AIPS, but as computers continually decrease in size and increase in computing power, future advancements in this technology may make it a candidate for a soldier's visualization system.[V18-V21]

Advantages: Allows the viewing of more realistic 3-D images. Allows the conversion of 2D images to 3-D.

Limitations: Alternating frame technology has not been applied in any practical applications to date. In the two-camera mode, the cameras must be aligned within a small tolerance to achieve the effect. In the one camera mode, the camera must follow a straight, predictable path and must remain

steady, because the motion of the camera is used to generate the two different images which are combined to produce the 3-D effect. Three dimensional imaging is a mid-term, medium-risk technology.

3.3.7 Geometric Reasoning

Description: Geometric reasoning is an image processing technique in which a computer examines an image and identifies features in the image, such as primitive shapes, patterns, moving objects, etc.[V22,V23] The computer can then highlight detected items to improve clarity for the viewer, or send this information to other devices, such as weapons, to aid in their operation. Unlike image enhancement, in which the computer looks at the image as a whole without regard to objects, this system's objective is to interpret features on the computer screen as objects. [V24]

Applications: Sometimes a solider needs to function in an environment where vision is impaired by darkness, atmospheric conditions, smoke, etc. In such situations, it would be helpful for the soldier to see the outlines of faint objects. For example, soldiers wearing infrared gear see washed-looking images, making it difficult to identify objects. Geometric reasoning would outline buildings, cars, and other important objects to aid the wearer to aim at targets or locate points of interest. Objects in motion behind or to the side of the soldier could be identified by a geometric reasoning system looking through a camera with a fish-eye lens to alert the soldier to potential threats he cannot see in his immediate field of view.

Geometric reasoning might be used in conjunction with image enhancement techniques. The image would pass first through the image enhancer/compressor, then through the geometric reasoning system. Then enhancement and compression would lead to a clearer image and less computer memory for the geometric reasoning system to process.

A system employing geometric reasoning could also provide the soldier with estimates of object dimensions and object range. A position sensor could be mounted on the soldier's gun, which could interface with the geometric reasoning system and helmet display unit. The gun's crosshairs and a aiming point of a target determined by the geometric reasoning system would appear on the soldier's mask viewing screen, and the soldier would only need to line up his crosshairs to the aiming point to aim. A helicopter based target detection system called the VHSIC 3v-bit Mission Processor, is currently under development by Westinghouse. Also under development by Westinghouse and Martin Marietta is the ATD, or 'Aided Target Detection/ Classification system', a system which would detect and prioritize targets for operator approval and reaction[V6].

Advantages: Image enhancement techniques (previously discussed in section 3.3.5) take a passive role in helping soldiers understand what they are seeing. They clean up the image, but tell the user nothing about the image. Geometric reasoning, on the other hand, not only adds clarity but also actively tells the user about his surroundings by helping the wearer identify objects and features of interest.

Limitations/Developmental Risk: Like other image processing techniques, geometric reasoning requires that the computer read and interpret images in real time. Image processing techniques such as real-time image enhancement are currently not possible because current personal computer systems are not fast enough to cope with frame rates humans need to observe a moving picture (approximately 30 frames per second). Users of geometric reasoning, however, may not require the same rate as the image enhancement, because this system is only generating outlines superimposed on the image. If a system were to update at a lower rate, such as 4 frames per second, current computers might be able to accomplish this task. The main technical risk associated with developing such a system is that the computer processing power required may take several years to arrive. Geometric reasoning is a mid-term, medium-risk technology.

3.3.8 Virtual Reality

Description: Virtual reality (VR) refers to the immersion of an individual into a computer-generated environment, sometimes called "cyberspace". It can be described as a computer-synthesized, three-dimensional environment in which humans, once appropriately interfaced, may engage and manipulate simulated physical objects. A designer can create any virtual environment imaginable. The "virtual world" is an interactive, multisensory, environment where human-computer interactions are based on the ways humans interact with the real world.[V25-V33]

VR usually involves wearing a helmet-like head-mounted display goggles for visual output. Special sensor-laced gloves (or entire body suits) are used for the command input. Earphones, treadmills, mechanical arms, joysticks, bicycles, and a host of other props are used to enhance interactions in a virtual environment (see Figures D-26 and D-27).

In most VR systems, there are four major components involved in the simulation. A control station computer and associated software generates the virtual world and dictates the programmed actions of the objects within the world. This computer is responsible for processing the inputs generated by the movements of the user and regenerating the cyberspace accordingly. Sensors are incorporated into the system to track participant's actions and supply inputs to the control station

computer so it can respond to a person's movements. These sensors are located on the user and/or the support equipment involved in the simulation process. A graphics rendering engine produces the appropriate images based on participant's perspective and actions. Personal computers have been used to create virtual environments, but graphics and response times are slightly poorer. These images are displayed on video screens or within the virtual head gear. Finally, an audio system can be incorporated into the system to create sounds as they would be generated within the virtual world.

Virtual reality has been referred to as virtual world, space, or environment; cyberspace; telepresence; or immersive simulation.

There are a multitude of applications of VR that affect a variety of industrial markets. Communications applications include teleconferencing, telerobotics, tele-trouble shooting, and electronic globalization. VR can be used for more effective computer-aided design and modeling (allowing designers to evaluate whether a product can actually be built). Transfer of information and education can be accomplished through virtual libraries, museums, or virtual time travel. A rapidly growing market for VR will be the entertainment industry: video games, interactive television/movies, multi-user games, and sports.

The most promising VR market applicable to AIPS is training and simulation. The variations of computer-simulated environments are virtually limitless: flight simulators, automotive-related simulations, re-creating accident scenes, marine exploration, handicapped training, surgical simulations, etc.

The most advanced simulators in operation today are those used by the aerospace industry and military. With the high cost of current aircraft, VR systems provide inexperienced pilots with some "flight" time before they actually fly the aircraft. These systems provide multi-channel visual displays of the view from cockpit windows and can even provide a sense of the roughness of the simulated runways and climate conditions. The instructor can program in a wide repertoire of emergency conditions for the trainee to be faced with (see Figure D-28).

Such a system would have applications for AIPS in mission simulation, remote reconnaissance, and terrain preview applications. It would be very useful for detailing maintenance procedures, allowing a soldier to "walk-through" the procedure. Strike teams could preview the terrain, or view simulations of a mission while enroute in a plane or other vehicle. A soldier in a foxhole could safely explore the surrounding country with a remote robot, seeing and hearing everything to which the robot was exposed. Architects and designers already use VR by designing a building and conducting such "walk throughs" before the building is even built (see Figure D-29). A soldier or commander

could experience what another soldier was doing, then provide him instructions on what to do next. A VR system could be integrated with current or developmental protective masks so soldiers could experience a variety of conditions while wearing the mask, without leaving the room. Such applications would be relatively easy to implement assuming an AIPS would already include a computer system.

Advantages: The most obvious advantage to VR is that it provides realistic training and, depending on what is being simulated, at a relatively low cost. The complete VR system at Hines VA Hospital, which was used in barrier-free design of buildings for handicapped people, was only $30,000. For training simulation, not only is the trainee protected from personal injury, but expensive developmental equipment is also protected from possible damage caused by a completely inexperienced user.

VR could also be used for telepresence, the addition of computer-enhanced graphics to live video for the performance of activities over a long distance. In other words, a battlefield general could "experience" the front in real time while being located safely, miles away.

Limitations/Developmental Risk: The major limitation of VR is the computing power required to create virtual environments. Several factors impact computation requirements: graphics quality, level of interaction, real-time response, force feedback, multiple inputs, and sound features. The VR system we experienced at Hines VA Hospital consisted of a helmet, headphone, a dataglove, and a wheelchair on rollers. The virtual environment was an apartment interior with a kitchen, family room, bedroom, and bathroom. We are able to "wheel" through the computer generated apartment, open cupboards, drawers, and move things around. The graphics display was as good as many video arcade games. Image processing was close to real-time, but in rooms with more objects (requiring additional or smaller shapes), there was a slight lag-time when turning your head. Force feedback was not used during our demonstration, but the system is capable of this. As previously stated, this system costs $30,000, which consisted of two IBM 486 PC's, a data glove processing module, and an ultrasonic sensor for head movement. Researchers at Hines attended a computer graphics convention where they experienced image processing equipment for VR systems that could update images so quickly and in so much detail that they could pass for reality, and were as good or better than live video. In comparison, these systems cost upwards of $500,000.

As video graphics and image processing technologies advance, so will VR. The VR industry will grow rapidly, because of the wide variety of applications. Actual integration of the VR with AIPS is far-term with low-risk. Using VR for mask development is near-term, low risk. Thus, VR technology will be classified as mid-term, low risk.

3.4 COMMUNICATIONS

Communications during combat will include conversation between soldiers, short range communications within a unit, and long range communications between units. Current methods of military communications have drawbacks at both the individual and system level. Individuals wearing protective masks have difficulty communicating with one another because of degradation in clarity of speech and difficulty with personnel identification. Miniature speaker/microphone arrangements are commercially available that offer improvements over the current protective masks' voicemitters. However, there are drawbacks with these systems that have prevented them from successfully being implemented into a protective mask for military fielding, which include: background noise, power, durability, and user compatibility. For short and long range communications, radio frequency (RF) communications commonly in use today are subject to electromagnetic interference and are easily intercepted. Alternatives are needed at all levels of command, control, and communications.

Recent advances in communication technology make optical communications a viable alternative to RF signal transmitting and receiving.[C1] Voice recognition systems will provide a hands-free computer-user interface for communications and system control, thus allowing the user to concentrate and perform on other tasks. Binaural processing will improve hearing by making the user feel as if they are in a real environment. Wireless LANs may be applicable for close-in communications, and lasers may be used for distant communications, both of which offer a more secure form of data transfer.

Table 3-5. Summary of Communication Technologies

	TECHNOLOGY	DESCRIPTION
Not Considered	Amplified Receivers/ Transmitters[1]	Use of amplifiers to enhance signal transmissions.
	Bone/Throat Microphones[1]	Converting neck and throat vibrations into electronic signals.
	IR/Microwave/Satellite[2]	Satellite communications at various wavelengths.
	Cellular Systems[2]	Communications within specific regions using limited frequency bands

	TECHNOLOGY	DESCRIPTION
Considered	Voice Recognition	Computer recognition of a spoken commands (speaker dependent and independent).
	Binaural Processing	Simulated stereo sound from outside sources.
	Wireless LAN's	FM, infrared, or other means of near network communications.
	Laser Communications	Modulated lasers for line-of-sight communications.
Impractical	Fiber Optics	Modulated laser light passed through optical filaments.

1 Technologies being researched under the RESPO 21 program.
2 Technologies being researched under the SIPE program.

3.4.1 Voice Recognition

Description: Computer or electronic recognition of spoken words and generally labeled voice recognition. Voice recognition technology is relatively new and highly dependent on computer power. The advance of computer power in the next twenty years is expected to be more than adequate for developing this technology (see Section 3.5.1) - Advanced Data Processing). Several commercial devices that employ voice recognition technologies already exist. Two types of voice recognition exist: speaker dependent and speaker independent. Both are discussed below.

Speaker dependent voice recognition systems compare a person's spoken words with computer records of a person's speech. The advantages of this system lie in the areas of security and reliability. Everyone has a unique "voiceprint" which varies slightly but which is unique to a particular set of throat, mouth, and speech characteristics. However, these systems must be "trained" before use so that the computer has a record for comparison.

The surveillance of communication channels can be accomplished through speaker dependent voice recognition. A speaker on a secure channel can be monitored and identified by his voice characteristics. If his voice patterns match up with those in memory the transmission will proceed, if

not, the transmission can be terminated. Also the home base can identify a speaker just by their voice characteristics of their transmission rather than have them identify themselves over the air.[C2]

Most of the systems in use now are speaker dependent as a system can be tailored to a speaker's voice inflection, tone, etc. This tailoring makes it easier to recognize words as it is specific to one central user. Research is currently underway to broaden this base as much as possible.

Speaker independent systems can recognize words or commands independent of the person speaking. Anyone who could speak English could use the system, although errors can occur due to a speakers' accent. Such systems are often slower but are also more flexible: they do not need to be trained before use as speaker dependent systems do. Such technology could be used to access unclassified information, such as terrain maps. Research is now focussed on improving computer word recognition rates to an acceptable level for commercial use. Neural networks are being employed to help the computer look for patterns and decipher between different speaking characteristics.

Applications: Voice recognition can be used in just about any setting but becomes extremely useful in situations where the user needs his senses to be concentrated elsewhere. Such a situation would exist in total darkness or where the user is a considerable distance from the object being controlled. Another example would be where the user needs to concentrate on other tasks, such as flying a jet or driving a tank. While operating the vehicle the pilot or tank operator could easily switch the type of weapon desired by just speaking a word rather than having to look down and trip a switch. The time saved could be crucial. A commercial application of voice recognition is available in the cellular phone industry, for car phones. Instead of having to physically hold the phone up to one's ear, a microphone is installed in the automobile sun visor. The driver speaks "DIAL HOME" and the device automatically dials his home phone number. This enables the driver to keep his eyes on the road instead of looking down into the car to dial a number.[C3]

Researchers at Osaka University Medical School in Japan have experimented with video in addition to voice recognition. Alone, voice recognition was found to be about 80% accurate but when coupled with video it increases to around 92%. A video camera was placed in front of subjects' months, who spoke various word commands. The camera focused on the different mouth

shapes that were being formed. Coupling these two mediums together and implementing a neural network to decipher the visual images have greatly increased voice recognition (see Figure D-30).[C6]

Advantages: Voice recognition should require no advanced training of the user; it is easier to learn than most other input oriented systems.[C4] Operator efficiency can be improved tremendously. In the case of fighter pilots the ability to change weapons systems, change radio frequencies, controlling flight displays and so forth, all by a few simple words can give that pilot an edge over the enemy. He/she does not have to avert their gaze toward the cockpit to trigger these systems, a simple word will enable their use. Speech recognition can greatly reduce pilot workload; in one test, pilots were able to run a prescribed course faster and more accurately when speech recognition for radio control was provided.[C2]

Voice recognition can compliment any system where the user has to change the controls or input, instead of searching around for the right control the operator uses his voice as the input device. The ability to free up the user's eyes and hands would greatly benefit an AIPS system. Security can also be implemented as the system could be tailored to a user's "voice print" and made unusable by any unauthorized person.

Limitations/Developmental Risk: One of the most prominent limitations dealing with speech recognition is with the English language itself. English is one of the world's most complex languages with many problems encountered in recognition. Words may sound alike but be spelled different, or might be spelled alike but have different pronunciations. Also, the spoken word is continuous and speech might tend to run together.[C4] It is difficult for a computer to understand the differences between words in a sentence and between word beginnings and endings. Another problem exists in speaker independent systems, being that a computer will tend to make more errors if a person does not speak a "natural" language. It will have trouble picking up regional accents or mispronounced words. Most of the speech recognition being done at present involve matching sounds not understanding speech. Voice variations such as accents cannot be differentiated in these systems at present (see Figure D-31).

Speech recognition might not prove beneficial in all cases. Other forms of data recognition can prove to be quicker and more correct. This could change as computer speed and processing capabilities increase, but for now computing speed has made speech recognition somewhat slow. In a study performed at the Aberdeen Proving Ground, MD twelve subjects determined the range and azimuth of aircraft tracks on the tactical display and updated the identification of such tracks. The

results of the study show that a touch panel is the fastest medium with fewest errors while a voice recognition system is the slowest with the most errors.[C5]

Another limitation which would affect an AIPS type application is background noise. Situations in which AIPS would be implemented may be noise-filled, stressful environments. This background noise could cause problems, as the whole system depends on receiving a clear signal. Research through industry is being conducted at present to determine the extent of background noise and what problems it might bring forth.

Currently most systems being used are in office type settings and not in the rigors of combat. In combat, the rate and pitch of one's voice tend to change quite considerably as they become excited. In a dependent system this could greatly affect the results, as the "excited" voice may not match the original voice. In an independent system the user might start running words together as they become excited, making it difficult for the computer to differentiate words. Voice recognition is a near-term, medium-risk technology.

3.4.2 Binaural Processing

Description: Binaural processing is used in a mammalian auditory system to combine the slightly different audio inputs in the left and right ears into a coherent signal with spatial qualities. Although the input signals are generated from a common source, they stimulate the left and right ear drums differently. These binaural physical differences are called the interaural time difference (ITD), the interaural amplitude difference (IAD), and the interaural spectral difference (ISD). Much research has been done to model the auditory system's binaural processor with neural networks to better understand how these binaural differences affect the attributes of hearing.[C7] Two such neural networks are the Jeffress model and the stereausis model, which utilizes respectively the temporal and spatial correlations of the binaural signals.[C8]

The ITD and IAD affect several attributes of binaural hearing, namely lateralization, localization, and signal enhancement. Lateralization is the perceived lateral location of the audio image between the ears.[C9,C10] Varying the time or phase and amplitude differences between the left and right signals results in the perceived shift of the sound from the central position. Localization is the perceived location of the sound image in space. The subjective location of the sound depends not only on the ITD and IAD but also on other cues such as the differential action of the head turning or

the acquired knowledge of acoustic properties of "typical situations". Signal enhancement of a desired signal masked in noise is accomplished by changing binaurally the phase of either the signal or noise by 180 degrees. This allows separation of the signal and noise so that selective listening can be performed (see Figure D-32).

Applications: Commercial applications of binaural processing concepts are in the binaural recording industry. The recordings attempt to provide the listener with the same sounds having spatial qualities that would be heard directly from the source. The recording technique entails placing a pair of microphones in the ears of a dummy head, and recording the left and right inputs in separate channels. The separation of the signals are maintained all the way to the listener's stereo headphones. The final result is that the listener is sonically transported back to the source and thus experiences the full spatial quality of the sound (see Figure D-33).[C11,C12]

Both NASA and the Air Force have used the concepts of binaural processing to develop a three-dimensional auditory display system. The effectiveness of the 3-D auditory simulation was evaluated by testing a person's ability to selectively listen and spatially locate a desired signal masked in various other inputs and situated in a 360-degree sphere.[C13,C14]

For AIPS, binaural processing concepts can be used for localization of sound images by manipulating the interaural signal differences rather than the 3-D auditory display. Binaural processing integrated with noise filters, could provide soldiers with auditory protection and enhanced hearing.

Advantages: Binaural processing implementation provides a more realistic representation of the acoustic environment in terms of the spatial quality than either stereo or monaural techniques. It allows faster identification and location of sound images as well as more intelligibility in communication. Binaural processing integrated with noise filters will be valuable in a noisy environment.

Limitations/Developmental Risk: In binaural recording, an accurate representation of the sounds from the listener's point of view is highly dependent on the facial features and pinna (outer ear) shapes and dimensions of each listener as well as of the recording dummy head Thus the spatial quality of the sounds are different for each listener (see Figure D-34).[C11] Overcoming this phenomenon will be necessary for future implementation with an AIPS, in which "custom-fitting" each soldier with his/her own system is not practical.

Presently, a thorough understanding of how the auditory system processes binaural signals is lacking. Without a clear understanding, applications of binaural concepts are accomplished using

external methods such as manipulation of the acoustic environment, i.e.. the location of the recording devices or output speakers, rather than of the binaural signals themselves. Neural networks have been developed to model the binaural processor of the human auditory system, but no model has satisfactorily explained all the phenomena associated with binaural hearing. Thus more research is needed for implementation of binaural processing in AIPS and thus development is mid-term, medium risk.

3.4.3 Wireless LANs

Description: Wireless Local Area Networks (LANs) are systems for linking computers with other workstations and devices in nearby locations without interconnecting cables. Truly wireless systems use either radio or infrared light for data transmission. Radio transmission is typically achieved in a wide bandwidth in the UHF range (406-470 or 902-928 MHz).

Speed, power, range, and cost of commercial systems vary. Of those investigated, infrared systems transfer data at approximately 140 kbps (kilobits per second) to 16 Mbps and have a range of 70 feet. Radio systems are slower, at 9 kbps to 2 Mbps, but have a range of 300 feet to 100 miles (with repeaters). The cost of wireless LANs ranges between $300 and $5300.[C15-C18]

Applications: Wireless LANs are effective for office computer networks, especially when computers are often being added, removed, or relocated, or when running cable would be difficult or impossible. They could also used in land mobile or ship-to-ship applications.

This technology may be adaptable to AIPS interpersonal, intra-unit communications in order to transmit electronic data between individuals or to communicate with a central computer.

Advantages: The main attraction of wireless LANs is their flexibility. Without cable connections, computers can be very mobile. Workstations or devices can be quickly and easily installed or removed from the network. Wireless LANs allow networking when cable is not an alternative.

UHF radio can use spread spectrum technology and encrypted transmission to provide security.[C20] Infrared transmission is difficult to detect and intercept. Infrared also is being developed to allow data transmission speeds faster than what is normally achieved with cables.[C16]

Limitations/Developmental Risk: Both radio and infrared LANs have limitations. Infrared communication requires a line of sight between the sender and receiver, or between those and a common reflector. Alignment of the beam is critical, weather conditions may hinder communication,

and the current range is limited (one commercial system recommends a maximum of 70 feet).[C15,C16] LAN radio transmission is subject to interference, and it is currently much slower than cable transmission.[C15] The packaging of commercial LAN components may not be practical for an individual to carry. Although these limitations present challenges, some forms of wireless LANs may be implemented in an AIPS in the near term with relatively low risk.

3.4.4 Laser Communications

Description: Laser technology offers a broader and far-reaching spectra for forms of communicating than ever before. Future communication systems will incorporate such technologies as infrared transmission, specific radio frequencies, and transmission by laser modulated light. The basis behind laser modulated light is the interpretations of pulses of laser light in a direct communication link. Laser modulated light will become quite popular as it has infinite applications. With the addition of optoelectronics in computer chips, laser type communication may possibly be the information transmission and processing mode for the future.

Applications: The U.S government has sponsored R&D for the past 20 years to develop spaceborne laser communication systems using frequency-doubled diode-pumped lasers. The communication could be from a ground station to a satellite or spacecraft/aircraft or from a satellite onto a ground target or even to an underwater target. There has been an R&D effort for about 15 years to develop laser techniques for communicating between spacecraft/aircraft and submarines. Problems have arisen matching the right wavelength laser to penetrate through water.[C21,C22]

Point-to-point land based laser communications are being developed by the Army and Navy. The system is narrow beamed and extremely secure, transmitting both voice and data. Progress has been hampered by problems dealing with the battlefield and sea obscurants. On land, variants such as fog, dust and smoke can severely alter a communication. Problems with water-borne transmission include the severe backscatter of the sea.[C21]

Advantages: Laser communication provides a more secure communication link as the laser is a direct shot to the target versus a radio wave which has a broad range. Unless the opposition was directly in the laser's path of communication it would be extremely difficult to intercept any information. Also the total time of transmission is quite small compared to most other forms of communication. In laser communications the light pulse is less than 1 second.

Lasers can also be employed in some effect for the detection of chemical and biological warfare. This involves the use of tunable-laser-radar systems for remote detections of agents in biological or chemical weapons. The Army has developed a CO_2 laser-based chemical-detection system. The only drawback with this system is that the range of tunability is quite small and thus it does not have a wide range of agent application.[C21]

Limitations/Developmental Risk: Lasers would provide near instantaneous feedback and would be far more secure than current systems used today. Alternatively, short bursts of information may provide adequate contact. Unfortunately, these systems are limited to line-of-sight communications and by the horizon. At present the current limitations involve the medium which the laser travels through. Such impurities as fog clouds, dust, or smoke can obscure the information to be communicated. New wavelengths and satellite relays may provide solutions to these problems in the future. Other limitations include size and power constraints. As computing power increases these can be overcome, but there is a limiting factor that will be reached with current computing techniques.[C21] Scientists at IBM are currently examining switching processes at the molecular level, which is the limit for current modes of computing. As for speed, we are constrained by the speed of light.[C22] Laser communications will mature as the military and industry identify more specific applications, which will propagate research into identifying lasers practical for AIPS applications, such as ground-to-ground or ground-to-air communications. Laser communication is a mid-term, low risk technology.

3.4.5 Impractical Communication Technologies

Fiber Optics

Optical fibers are composed of a center core through which digital data is transmitted as a series of light pulses. Cladding over the core prevents light from escaping and an outer buffer layer provides protection from environmental exposure. Advantages to fiber optic links are their high data transmission rates, non-radiating transmission signature, immunity to electromagnetic interference, and their light weight compared to conventional cables. However, attempting to link soldier-to-soldier via fiber optics would be extremely difficult and very impractical, thus fiber-optics were not considered in the AIPS evaluation.

3.5 SYSTEM CONTROLS

This section of the report discusses technologies that will be useful in integrating technologies discussed in previous sections. Table 3-6 lists and describes briefly technologies identified during the evaluation.

Table 3-6. Summary of System Control Technologies

	TECHNOLOGY	DESCRIPTION
Not Considered[1]	Body Armor, Powered	Advanced full body armor system.
	Digital Video	Advanced video capabilities.
	Active Badges	Monitoring and identification through an electronic badge system.
	Visual/Audio Scanning	Scanning technologies used to supplement voice and vision.
	Graphical User Interfaces	Ability to upgrade from 2-D to 3-D makers user feel more at ease with system.
	Computer Thermal Control	Controlling temperature throughout the computerized system.
Considered	Advanced Data Processing	Advances in analog and digital processing equipment for vision, communications, and system controls
	Neural Networks	Continuous, real time analog data processing (analog neuroprocessors).
	Optoelectronics	Wiring and circuitry based on light impulses rather than electric charges.
	Fuzzy Logic	Using digital computers for analog-type data processing.
	Artificial Sight & Optical Imaging	Brain stimulation to enhance bodily functions and obtain human feedback.

1 These technologies were either impractical or describe general methods for implementing technologies discussed in previous sections. Although these technologies were not considered in the evaluation, they are described briefly in Section 3.5.6.

3.5.1 Advanced Data Processing

Description: AIPS will require advanced computer data processing for system controls, video displays, and communications. The computing unit for AIPS will have to be compact, light weight, and capable of rapid data processing. Advanced data processing includes any technologies that offer potential for increasing process time or reducing the size and weight of current computing hardware. New developments in this area include the use of holographic memory and advancements in optical disk speed and capacity. Other technologies in this area include neural networks, optoelectronics, and fuzzy logic (discussed in sections that follow). Only a limited application of these technologies exist in commercial products today. However, they all offer significant improvements in computer technology, which will be a great benefit for an AIPS.

Applications: Currently Bell Communications Research Inc. is refining a holographic memory system they have developed. The system will enable chips to contain 10 times the current capacity and enable them to receive data 1000 times as fast. Holographic imaging can store a greater amount of data in virtually the same size system. With the use of lasers, greater speeds can be achieved to create holograms, this has led to further research for use with optical neural networks. Currently the laser is separated into two separate beams with the information in the form of an optical image carried in one of these beams. The other beams serves as a reference beam. Light regulating modulators combine the two beams inside a crystal to create the three dimensional holographic images. These images can be retrieved in a moments notice when illuminated by the reference beam. [S1]

Using optical technology, advances have been made in other areas. The use of this technology has increased the amount of data that could be stored while decreasing the amount of time required to access it. Optical systems pick up pulses of light rather than electronic signals. Several companies have been exploring these types of systems and have made advances in regard to speed and capacity.[S2] AIPS can benefit greatly from this speed increase, especially in the case of neural networking.

Another company, Velox Computer Technology, has been able to increase the clock speed of their processors by using a cooling system called ICEJET, which employs thermoelectric cooling (discussed in Section 3.2.4). The system cools the chip down to permit it to process at higher speeds. Hitachi has developed a process called "x-ray lithography" to etch lines of 0.1 micron, which they say will enable them to produce a one-gigabit chip by the year 2000. [S3,S4]

Advantages: The use of holographic technology will allow the data processing unit to operate much faster. Also more data can be stored in the same amount of space than before. Advantages with optical systems are that in picking up pulses of light they generate less heat than current processing units and thus do not have as great a need to be cooled down. New computer systems will offer quicker response times, more data storage capacity, and be available in smaller volumes.

Limitations/Developmental Risk: Each individual system has its own limit as to speed and capacity with new advances going toward improving efficiency. The research and development of the electronics industry will spur advances in computing technology, especially in microelectronics. Based on the historical evolution of computing technology to date, it is not unrealistic to predict that hardware with today's PC capabilities will be the size of pocket calculators in the year 2020.

3.5.2 Neural Networks

Description: Future data processors will need to work on a real time basis with analog signals. For example, consider a vision system that processes data from various optical sensor inputs then projects an image onto a video display screen directly in front of a soldier's face. If a soldier turns his head, the image he sees should be the scene directly in front. A time lag in processing the scene directly in front of the soldier could be fatal. Neural networks can work to reduce and eventually eliminate this time delay.

Neural networks can process analog data continuously, while digital computers must sample the analog data and then after processing, attempt to "smooth" the data over the unsampled time. For this reason analog neuroprocessors (ANPs) will be favored over today's digital computers. ANPs are modeled after biological neural networks. They are adaptable to many different applications. One of the greatest advantages to neural networks is their ability to learn and compute based on what they receive from an outside stimuli. They may also be extremely valuable for communications and vision systems of the future.

Applications: Cognex has developed a system which uses artificial intelligence techniques to modify a vision procedure that the firm calls searching. Instead of resorting intensive calculations to compare a stored image with a sample image, Cognex scans the sample at low resolution and uses artificial-intelligence-based algorithms to guess where the object should be within the image. This

could be used to identify and analyze detailed surveillance-satellite images. Therein also lies the possibility of combining this type of system with infrared and radar thus improving the subjects "night sight".(S5)

Cincinnati Millicron has been developing a machine vision system which scans an object for manufacturing. The system is capable of perceiving depth in real time as it moves. When coupled with a neural computer, the system can prove to be quite effective. Currently they have implemented neural networks in robot guidance, flaw identification, inspection, and welding.(S5)

Two researchers have refined a system which trains the neural network using the self-organization method of unsupervised learning. This type of system generates feature maps for pattern recognition. The system is currently in the research stage but delivers speed at a relatively low cost.(S6) Such a system could enhance a soldier's vision to help spot the enemy. This automatic target recognition can help a soldier identify a fighter plane, an armored vehicle, or another soldier.

Several neural networks have been applied to computer vision systems by the Worcester Polytech Inst. Various models are presented of which several have been simulated on a computer.(S7) Work has also been done concerning speech recognition, sonar signal identification, and seismic signal discrimination.(S8)

Advantages: The ability of neural networks to emulate the human brain makes them adaptable to just about system where input is received and needs to be acted upon. Also neural networks have tremendous identification capabilities that a human can miss due to monotony, small sample size, or clarity. Neural networks have proven quite beneficial in vision systems due to their learning capability as well as their capability of "real-time" data processing, which will be exploited greatly in the coming years as computer speed increases.

Limitations/Developmental Risk: Most of the neural networks currently used are industrial based and very simple compared to what could be implemented in theory. Most of the systems being developed at present are only capable of low-level recognition. More research needs to be done to implement the numerous theories presented.

More promotion of the project is needed to maintain funding necessary for development, as large scale design and programming of neural network chips have not materialized. Neural networks are a mid-term, medium risk technology.

3.5.3 Optoelectronics

Description: Another radical departure from traditional electronic computing is the introduction of optical computing components that use light as the working medium rather than electrical charges. The field of optoelectronics may soon provide a completely optical computer. The light is generated by a single laser, and the light follows waveguides smaller than today's circuit pathways. These waveguides may be etched in a manner very similar to the process used to etch circuits. Optical computers will be smaller, lighter, produce less heat, and require less power. Optical computers will also be faster and more reliable as electromagnetic interference will be eliminated.

Applications: It has been proposed in an AT&T Bell Lab report that the movement of large amounts of data will not be possible without optics and that the computer industry will eventually reach a limiting factor with its current method. Optical switching and the use of fiber transmission will make large data transfers possible.[S9] Aircraft will have the benefits of fiber-optic control to transmit noise free, high speed data between a multitude of computers as well as audio and video information to the flight crew. The Navy and NASA currently have a joint venture called FOCSI (Fiber Optic Control System Integration) to build and test flight sensor systems for propulsion and flight control.[S10]

Mitsubishi Electric Corp. has successfully tested an optical neural network chip that they claim can store self-learned knowledge for 20 minutes. Researchers created the device by fabricating eight optical arithmetic elements and 64 optoelectronic memory elements onto a gallium arsenide substrate. The arithmetic units process the data as light, and the memory units convert the results to electric signals for storage. The part operates at 2,000 times the speed of a personal computer.[S11]

Advantages: Optoelectronical systems provide data transfer with virtually no magnetic interference and at a much lower power.[S12] This immunity to electromagnetic interference would result in more secure communications and more reliable transfer of data.

Benefits to AIPS would include size as an optical based system would be much smaller and weigh considerably less than an electrical based system. Another benefit to AIPS would be the ability to produce lighter and cooler computers with more compact circuitry. Also the systems presented could be put in high explosive and high magnetic environments such as fuel areas. The chips themselves would not produce short circuits or ground loops, and the threat of fire is minimized.

Limitations/Developmental Risk: According to one published report it is difficult to pass information from an optical module operating at near maximum throughput to other parts of a signal-processing system.(S13) Optical modules do not yet have the capability to perform nonlinear operations on partially processed data that would greatly reduce the module output rates. The same paper goes on to say that this can be taken care of by reducing precision requirements by using various adaptive learning techniques such as neural-net models. Industrial acceptance of optoelectronics is low at present with most of the effort in the research stage and limited to prototype demonstrations. This attitude is slowly changing with one scientist describing it as "a critical emerging technology" that is slowly gaining momentum.(S13) Optoelectronics is a mid-term, low risk technology.

3.5.4 Fuzzy Logic

Description: Fuzzy logic contrasts with digital logic in that inputs can be somewhere between one and zero. For example, a digital analysis of an image may separate all the pixels into either a "white" or "black" pixel, whereas a fuzzy logic analysis would be able to include an infinite range of grays in between the white and black. The general concept being that computers can act on percentage membership in a set, rather than simple yes/no criteria.(S14)

Applications: An AIPS could employ fuzzy logic in environmental control, image processing, and communications. Greater control exists with fuzzy logic as the system acts on percentages and not true-false logic.

Advantages: Fuzzy logic tends to be more robust and fault-tolerant. It is capable of more flexible operations over time versus simple yes/no type logic. Fuzzy logic systems could provide enhanced data analysis over current digital systems.

Limitations/Developmental Risk: Part of the problem is programming a digital computer to perform fuzzy logic operations. With some of the mathematical models proposed the error increases exponentially with the number of stated variables. Fuzzy logic has been used in only a few commercial products. Most of the effort is now in the research and development stage. Analog computers may increase the use of fuzzy logic.(S15-S16) Research has been shifted to developing neural networks, which can actually do analog processing, as opposed to simulating it. Fuzzy logic is a mid-term, high risk technology.

3.5.5 Artificial Sight & Optical Imaging

Description: Research on the brain itself is still in very primitive stages but much has been learned about how the brain operates and processes information. Studies are limited due to the availability of subjects. Some research has been done into the brain's ability to produce and interpret vision. Several blind volunteers agreed to an artificial sight study in which small electrodes were placed onto the back of their brain to enhance vision. Also several epileptic patients participated in an optical imaging study in which light was shone onto the brain itself and thought processes were able to be observed.

Applications: Regarding the vision study, researchers placed small electrodes onto the brain. A small camera was used as the "eye" for the electrodes which sent back signals to the brain. The signals were translated into phosphenes which the brain reacts to and transposes into sight. Most of the volunteers described seeing crude objects while some were able to see the horizontal or vertical lines in a television set (see Figure D-35).[S19]

In optical imaging researchers were able to directly view human thought processes, tracing the complex pattern of electrical and chemical reactions to small clusters of brain cells. During surgery on epileptic patients, the doctors directed a reddish light directly onto the brain, and photographed it using a highly sensitive electronic imaging device. By comparing the pictures during a mental activity with the pictures either before or after it, a computer highlighted the subtle differences in reflected light. These differences represent the brain at different levels of thought.[S23]

Advantages: Most of the work in both of these areas is very limited but the future is very broad and far reaching. As the thought processes of the brain are mapped, more of what is found can be applied. In an AIPS, the system itself could conceivably be controlled just by thinking what you want it to do. For example, if you start "feel" hot, a cooling fan automatically turns on inside your unit. This may sound far-fetched but it is the ultimate goal of the researchers involved. With vision enhancement, a camera could be developed that enhances the wearer's current vision, allowing the user to see objects quite far away, retain his vision during night-time operations, or help him to filter out undesirable objects.

Limitations/Developmental Risk: As stated before these systems seem extremely far fetched for soldier integration, but cannot be overlooked. A system capable of responding to a soldier's thought could be invaluable. Most of the research being performed is being geared toward mapping the brain and understanding "how" it works and not on how it can be harnessed. Also the availability of experimental subjects is somewhat of a problem as volunteers are tough to come by for medical safety reasons.

3.5.6 System Control Technologies Not Considered

Body Armor - Powered

The advanced body armor that a soldier of the future would wear would include many of the systems described before, neural networks, artificial sight, etc. Much work has been done with exo-skeletons in the area of lift enhancement (lifting heavy loads). Parts of this system could be used to help a soldier lift objects, but would also encumber him.[S19] In a report by DTIC they encounter some of these ideas. While a fully encapsulated soldier would be protected from chemical/thermal/etc. threat, they fear that an exo-skeleton might isolate the soldier from their environment.[S20]

Digital Video

Digital video is the process of converting live video from a TV, VCR, or camera into a digital signal for display on a personal computer. The problems encountered with digital video rests in the amount of memory and space it takes up. On a standard system, a 5 second image would take 40-50 megs of space. Apple Computers is working to change this, as they have indicated a desire to develop products in this area.[S21] Digital audio for the time being has taken precedent in development and seems to be the more worthwhile innovation considering the current level of technology.

Active Badges

An active badge system is a small (credit card size) badge which sends out an infrared signal every ten seconds. This signal then is sent to a central computer and can be used to locate a person wearing a badge. Features of the system include routing phone calls to a phone near that person, opening doors for authorized persons only, and access to certain levels of information on various computers throughout the office. Drawbacks include a right to privacy and security, with the computer not being able to tell if the person authorized to wear that badge is actually the one wearing it.[S22]

Visual and Audio Scanning

Optical character recognition (OCR) scanners have been developed which can scan a typed document and turn the document into a synthesized voice. Progress has been made dealing with digitized tablets, voice input boards, audio input devices, while other technologies like a force sensing spaceball have been created. Most of this work is done to give the user greater interaction between himself and the computer. Voice recognition is now possible as is force sensing by means of a spaceball. More companies are making use of the advances in computer input devices that convert analog signals into digital data.[S23]

Graphical User Interfaces

As computers become more and more complex it is necessary and possible to enhance the graphical output one views on the screen. It is also necessary to make that output as simple as possible so even those with virtually no computer experience can comprehend and manipulate. Virtual reality is the ultimate goal of interfacing, but in the meantime several Japanese companies have used virtual reality interfaces in the creation of other systems. One such system draws a 3-D mask which moves and speaks in nearly real-time.[S24]

Computer Thermal Control

A liquid heat sink has been developed for thermal control of computing systems. The heat sink serves as a path to carry heat from components through housing to ground. The system consists of multi-layered metallized plastic film with fire-retardant properties. Convection current carries heat energy to opposite surface for transfer to cooler surface.[S25]

Researchers at Tuffts University have developed a "smart" window which lets in heat and light according to temperature. Using relatively short pulses of electric current the window varies the transparency to allow in more light during colder months while reflecting light during warmer months.[S26]

4.0 CONCLUSIONS

4.1 RESPIRATORY PROTECTION

Future battlefield threats may be difficult to identify as novel nuclear, biological, and chemical weapons are developed. Thus alternatives to mechanical/chemical filtration methods used today need to be investigated. In order to provide respiratory protection to soldiers of the future, some type of self-contained breathing apparatus may be required, either in the form of oxygen storage or oxygen generation.

Current oxygen storage techniques include compressed oxygen, compressed air, and mixed gas. The critical shortfalls of these methods are size and weight of the storage containers and limited protection times, which make them impractical for use with an individual soldier today. Major advancements in lightweight, high-strength materials are needed to reduce the weight of current oxygen storage containers. High pressure and cryogenic oxygen storage present potential improvements to today's oxygen storage techniques.

An alternative to oxygen storage is chemical oxygen generation from superoxides, which react with moisture and carbon dioxide in exhaled air to generate oxygen. Effective use of superoxides for chemical oxygen generation requires proper storage because atmospheric air contains the ingredients for reaction. Chemical oxygen generation also creates the problem of heat addition to the air, which makes the air unpleasant to breath without a cooling system. These superoxides are currently used in closed circuit rebreathers, which are generally lighter in weight than other systems, but also more expensive and harder to maintain.

Research is being done on the electrolysis of water vapor for oxygen production. Combined electrolysis of CO_2 and water vapor has been achieved. Of the few respiratory protection technologies identified during the evaluation, these appear to be the most promising for AIPS. The majority of current research in this area is being funded by NASA, for future space station applications. For AIPS, research needs to be done to develop an electrolytic cell that requires little power and minimizes heat generated during the reaction. A lightweight, small volume system will be needed. Oxygen generation from water vapor electrolysis could be combined with oxygen generation from carbon dioxide in a closed system, for complete regeneration of exhaled air. Additional oxygen could be generated from moisture vapor trapped inside a soldiers protective suit, which would provide limited body cooling.

Additional research being done with space stations is on the use of plants and algae to generate oxygen in a bioregenerative support system. These conceptual space systems are on a much larger scale than AIPS. However, perhaps some small plant life such as algae, moss, fungi, or even bio-engineered bacteria could, in the future, provide enough supplemental oxygen and carbon dioxide consumption for a rebreather system.

Regardless of the method of oxygen supply used, a rebreather would be recommended for maximum use of the sources. All rebreathers must address the problems associated with the high humidity generated in the exhaled gases. This may lead to fogging of the visor/faceplate and water condensation within the "breathing bags" used by rebreathers to maintain a constant volume within the system as the lungs are expanded and contracted. Most likely, respiratory cooling will be needed for rebreathed air, oxygen generated from superoxides, or oxygen generated from electrolysis.

It is difficult to predict where the technology will be for these conventional systems twenty to thirty years in the future, especially considering the slow rate of development in previous years. Work is being done to decrease the size of CO_2 scrubbers from the use of new chemical processes and air flow patterns to also increase scrubber efficiencies. Research in the area of respiratory protection seems very limited, particularly for land use. Most research is now government sponsored for underwater and space exploration. Thus, advances made by the commercial respiratory protection industry will be needed to benefit AIPS.

4.2 THERMAL MANAGEMENT

MCC is currently the most commonly used method for individual cooling. Application of MCC for the military include air and liquid cooled vests worn by aircraft pilots, CVC personnel, and explosive ordinance disposal personnel. These systems either supply conditioned air to a garment lined with air distribution manifolds or recirculate a working fluid through a garment lined with tubing. Both types require a cooling source and a pump/blower to move the working fluid. The systems are fairly bulky, thus preventing them from being added to the soldier's load bearing equipment. Breakthroughs are needed in personal cooling to reduce the size and weight of current cooling units or new clothing material technologies.

AIPS' thermal management system will need to be capable of one or all of the following: respiratory cooling, suit cooling/heating, and equipment cooling. Technologies that offer alternatives to current methods of cooling are phase change materials (PCM's), heat pipes, and thermoelectricity. These technologies are also effective for heating.

PCM's rely on latent heat of fusion to absorb heat for cooling or release heat for heating. They are generally so they are not lost to the environment when they change phase. These capsules (available in microscopic form) can be used to fill "pockets" in clothing (for passive heat exchange), or are mixed with a liquid to form a slurry (for active heat exchange) that can be pumped through channels or tubes woven into clothing.

Heat pipes are an old technology getting a second look. They are very simple devices that rely on latent heat of vaporization. This simplicity makes them very reliable. Heat pipes operate between a hot source and a cold source, even at small temperature differences (~5 °C). The heat source "boils" a liquid, the vapor expands through a tube to the cold source where it condenses and flows back to the heat source. Early forms of heat pipes were called "thermosyphones", which used gravity to return the liquid to the heat source. There are many variations of the basic heat pipe idea, including use in satellites and in innovative cold-weather gloves that transfer heat from the elbow region to the fingers to prevent frost-bite.

Thermoelectricity (TE) has also been around for a long time. TE is the production of a thermal energy from electricity. The fundamental TE unit is a TE chip, which is made up of tiny TE materials aligned in a way such that as a direct electric current passes through the chip, cooling is accomplished. Heating is accomplished simply by reverse direction of the current. The most common application of TE chips is cooling small electronic components.

There were not any "novel" methods of thermal management identified during the evaluation. Thus, the future lies in developing applications that employ existing technologies. Research in industry will certainly continue to discover new materials for PCM's, heat pipes, and thermoelectricity. Passive systems will have advantages of reliability, little or no power requirement, low maintenance, and ruggedness. The use of multiple PCM's interwoven into clothing may provide a wide range of heating and cooling for thermal comfort. Micro heat pipes woven into clothing may help create nearly isothermal skin temperatures. These heat pipes could then be connected to a central heating/cooling site. Lightweight heat sinks (PCM's) could be carried that could be "plugged in" to the suit when the current heat sink was filled/emptied, or when a different base temperature is desired. Thermoelectricity can be employed with AIPS in a variety of ways; heating and cooling

applications will require a DC voltage source. The basic technology for a thermally controlled suit already exists. The future will require research into finding materials that operate effectively at near ambient temperatures, and in improving efficiency to allow for extended operations.

4.3 VISION/OPTICS

The AIPS vision system will be required to provide enhanced vision and eye protection for the soldier. This may be accomplished by integrating current protective masks with heads-up displays and protective eyewear, or by developing a mask that enables a soldier to place a "video screen" over his visor that graphically recreates his surroundings.

Current optics technology has been applied to night vision goggles, weapons, sights, heads-up displays, and new miniature computer screens. Computer screens the size of credit cards that can be placed in front of one eye are already in production. New methods of projecting computer images with vibrating mirrors, LED's, and laser diodes are being researched.

If development of protective eyewear for the soldier can not keep up with advancements in direct energy weapons (e.g., lasers), a vision system capable of both filtering out harmful effects and providing a graphical display from optical inputs will be needed in the future. A system of this type will depend heavily on advancements in image processing and optical sensor technology.

Image processing is necessitated by the lack of sensors with an image quality that matches the human eye. Neural networks and innovative computer algorithms are being developed to enhance sensor images. Image compression is included in this area because of the need for a computer to store and analyze several frames of imagery to accurately enhance moving images, and AIPS may be limited in computer memory.

"Intelligent sensors," photosensors embedded in a neural network to improve image sensing by approximating the human eye, and thermal imaging are research areas attempting to improve vision systems. Combining and comparing different images may help computers identify objects. Three-dimensional imaging overlaps with the research being done in virtual reality. Three dimensional images displayed on a computer screen are more realistic and could provide much more information to the viewer. Geometric reasoning could be used in identification of enemy equipment from only a limited amount of video input.

An AIPS vision system could integrate several technologies mentioned above to provide the soldier with enhanced vision, eye protection, and identification in all operating environments by replacing the current see-through visor with a computer controlled screen. Advancements in image intensifier tubes (night vision goggles) and intelligent photosensors, integrated with a neural network, will enable a live scene to be completely recreated with video graphics. Three dimensional imaging could be added to give the viewer depth perception. Geometric reasoning could assist the soldier in identifying signatures of items in the field of view.

Image data processed by the AIPS vision system could also be transmitted, in real time, to other soldiers or the command post, thus allowing others to "experience" what the soldier is seeing. This data could be recorded and later used in a virtual reality combat simulation.

The development of a high-tech vision system for AIPS will be limited by the size, weight, and power needed to operate the data processing equipment that integrates visual display technologies. The size and weight shortfalls will be overcome by advancements in microprocessors and microelectronics for the computer graphics industry. However, advancements in individual power do not appear as promising.

4.4 COMMUNICATIONS

The AIPS communication system will need to integrate the soldier to his computer, to his squad, and to his commanding officer. In addition, the system will need to provide the soldier with enhanced hearing capabilities and auditory protection.

Current research in the area of communications is focused on voice (speech) recognition systems, binaural processing, local area networks (LAN's), and lasers. Significant research in the area of auditory enhancement was not identified.

Computer controls activated by human speech are being developed. Emphasis is on creating a system which is speaker-independent (not limited to a single person) for performing computer commands. Speaker-dependent systems will still be used for security purposes. Voice control of computer systems would allow hands-free and semi-eyes-free computer manipulation. Voice synthesis is improving at the same time. Computers for AIPS may be controlled entirely by voice commands and could provide a great deal of information back to the user by voice, as opposed to sight, which requires leaving other tasks to read a heads-up display screen.

Binaural processing is a computational method for creating spatial effects sensed by the human auditory system. Binaurals, integrated with neural networks, will allow soldiers to maintain complete auditory perception, even when wearing protective head gear.

Wireless LAN's are being developed that may have potential applications for AIPS in close-combat ground operations. Current wireless LAN's use either radio frequency or infrared signals for inter-office operations.

Lasers are useful for safe, accurate rangefinding, target identification, and some secure communications. Unfortunately, communication must be point-to-point and is often limited by obscurants (smoke, dust, fog) and often requires a lot of power which makes the systems very bulky. As laser research continues, AIPS applications for communications may emerge.

Advancements in communication technologies will derive from industrial research efforts. Much research is being done on ways to improve the quality and efficiency of domestic and global communication systems. The only real challenge for AIPS is integrating technologies available in the future. A communication system for AIPS will have capabilities for both long range and short range transmitting and receiving. AIPS may also employ an enhanced auditory filter that would amplify selected sounds, such as nearby voices, and remove offensive or dangerous background sounds, such as helicopter rotors or explosions.

4.5 SYSTEM CONTROLS

In the year 2020, AIPS will require more than a simple feedback control system with sensors, switches, and display gauges. Most of the technologies discussed in section 3.0 will need to be controlled and operated by a central or individual computing system. The potential of some of these systems depends on the CPU's speed, storage capacity and tolerances to heat. If the CPU is soldier mounted then size, weight, power, and durability will need to be considered.

The speed of the processing chip will be essential to AIPS. Faster and larger capacity chips are constantly being introduced in the marketplace. The need for real time signal processing and computing exceeds current capability. Real-time processing is within reach. While we are nearing real-time processing, the research community is approaching a limiting potential on the current generation of computer chips. In the future, chips will work on the molecular level making it virtually impossible to downsize any further.

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Computer power is constantly being compressed into smaller physical sizes. The typical desktop micro-computer already has much more capabilities than the 1960's mainframe, which filled a room. Random access memory (RAM) capability quadruples about every two to three years. In the case of personal computers, the progression through the 1980's has been from 16 kbit, through 64 kbit, 256 kbit, 4 Mbit, to 16 Mbit RAM currently available, with 64 Mbit RAM within sight.[10] The computing power available from future computer chips will greatly exceed AIPS requirements for data processing.

Computing power will be enhanced greatly with neural networks, which would make use of computing advances as larger and more complex neurals could be developed. Neurals will be able to simulate human thought processes and learn from the actions they perform or mistakes they make. This will greatly increase the effectiveness of the individual soldier. Neural networks could be incorporated into other AIPS technologies that would benefit from computer assisted "thinking".

A neural network could monitor sensory input from AIPS' subsystems to learn a soldier's physical behavior. For example, a respiratory system integrated with a neural network could memorize an individual's breathing pattern under normal and stressful conditions. When these conditions are encountered again, the system would remember how much breathing assistance was needed, thus optimizing use of oxygen (or other air supply). In an AIPS visual system where a soldier's immediate surroundings are recreated on a screen in front of the eyes (requiring real time processing of images), neural networks could be used to enhance process times without consuming all of the CPU's memory. In AIPS' communications, neural networks will enhance voice recognition systems where the computer can "learn" individual's voices, which will increase speech processing. Neural networks could be used in battlefield management, in which a squad of soldiers would be continuously updated on the status of their position with respect to one another and the enemy.

Optoelectronics is another technology that will enhance signal processing and improve system effectiveness, with the medium of data transfer being pulses of light rather than electrical pulses. The main advantages being the absence of heat and interference from magnetic fields. The electronic signature of a soldier wearing an AIPS could be reduced significantly with the use of optoelectronics. Potential system failure caused by electromagnetic interference could also be reduced.

While new device technology will provide far-reaching capabilities, equally important is the packaging, assembly, and interconnection of multiple micro-devices into a compact, integrated system. Advances in micro-machining of electronics and small devices will be needed to support

integration of these components into an AIPS. Future AIPS designers must evaluate the feasibility of downsizing high-tech system applications as they are introduced by the research community.

Hardware for future control systems will be much smaller and have increased capacity over today's system. Up to now, manufacturers have kept up with advancements in the electronics industry and will probably continue to do so. Thus, most, if not all of the technologies mentioned here will be developed enough for AIPS application.

A critical factor in designing system controls for an AIPS will be availability of power. Major breakthroughs are needed in the area of individual power, to support the integration of future technologies discussed in this evaluation.

5.0 RECOMMENDATIONS

Table 5-1 lists technologies considered applicable to AIPS and our suggested plan for ERDEC's utilization of these technologies. The three recommendation categories are presented below. Recall that risk definitions were presented in Section 2.5.

Define Further: ERDEC should conduct or fund an additional investigation in the near term into this area. The technology is likely already there or is being advanced elsewhere. However, the precise payoff to ERDEC is not clear, and the required independent advances are not well known.

Exploit: The concept and/or associated technologies are in early development, but appear very promising for far-term implementation. Coordination with the sponsoring organizations is required and suggested to define needs. ERDEC funds could enhance the rate at which this technology matures.

Monitor: ERDEC should not fund any research in this area, but should be prepared to exploit advances being made. No ERDEC funds are necessary to spur development, although ERDEC funds may be necessary to actually extract and utilize a given technology as it matures.

Table 5-1. Summary of Technologies, Risk Assessment and Recommendations

Technology	Risk	Recommendation
Oxygen Storage	Near-term, medium risk	Monitor
Oxygen Rebreathing	Near-term, low risk	Monitor
Oxygen Generation from CO_2 using Superoxides	Near-term, low risk	Exploit
Oxygen Generation from CO_2 using Electrolysis	Mid-term, medium risk	Define further
Oxygen Generation from Water Vapor Electrolysis	Mid-term, medium risk	Exploit
Oxygen Generation from Plant/Algae Growth	Far-term, high risk	Monitor
Phase Change Materials	Near-term, medium risk	Exploit[1]
Heat Pipes	Mid-term, low risk	Exploit[1]
Thermoelectricity	Mid-term, medium risk	Exploit[1]

Technology	Risk	Recommendation
Image Intensifier Tubes	Near-term, low risk	Monitor
Heads-up Displays	Near-term, low risk	Exploit[2]
Scanning Mirrors	Near-term, low risk	Monitor
Intelligent Photosensors	Mid-term, high risk	Monitor
Image Enhancement/Compression	Far-term, medium risk	Monitor
3-D Imaging	Mid-term, medium risk	Monitor
Geometric Reasoning	Mid-term, medium risk	Monitor
Virtual Reality	Mid-term, low risk	Monitor
Voice Recognition	Near-term, medium risk	Monitor
Binaural Processing	Mid-term, medium risk	Exploit
Wireless LAN's	Near-term, low risk	Monitor
Laser Communications	Mid-term, low risk	Monitor
Advanced Data Processing	Mid-term, medium risk	Monitor
Neural Networks	Mid-term, medium risk	Define further
Optoelectronics	Mid-term, low risk	Monitor
Fuzzy Logic	Mid-term, high risk	Monitor
Artificial Sight and Optical Imaging	Far-term, high risk	Monitor

1 Need to monitor NRDEC's MCC programs.
2 Need to monitor NRDEC's SIPE program.

For technologies that should be "monitored", current research efforts and active organizations are contained in Appendix E. Occasional contact with these organizations will enable ERDEC to stay up-to-speed on state-of-the-art technologies. Additional information and program plans on technologies that should be "exploited" or "defined further" is contained in Appendix F. This information will be useful for establishing basic research programs for maturing these technologies for future implementation into an AIPS.

This document will serve as a database for technologies applicable to an individual protection system of the year 2020. At a minimum, all technologies should be monitored for hardware development, especially for vision and communications. The commercial industry will continue to introduce electronic "gadgets" and "gizmos" that may have applications related to AIPS. Effectively monitoring these technologies can be done by periodically reviewing some of the science and engineering journals listed previously in Section 2.3.

6.0 SYSTEM CONCEPTS

The technology evaluation for an Advanced Individual Protection System (AIPS) for the year 2020 focused on technologies that could provide enhanced respiratory protection, thermal management, vision, communications, and system control to the individual soldier. Thus, system concepts presented in this section deal primarily with head and neck protection, rather than full body protection. A protective suit will be an integral part of an AIPS and must not be overlooked, however, protective material technologies were not addressed in this evaluation. Because the AIPS evaluation dealt with technologies not fully developed, we have the flexibility to create various concepts for technology integration.

Current head protection, respiratory protection, eye protection, vision enhancement, and communications are provided to the individual via separate hardware components: helmet, protective mask, laser protective goggles, night vision goggles, and radios. A future system may integrate all of these features into a single system. In congruence with other Army programs, such as SIPE and TEISS, a modular approach will be taken for AIPS.

An AIPS will consist of a respiratory protection unit, a helmet with enhanced vision and communication systems, a thermal control system, an individual computer for system control, and power unit, as shown in Figure 2. The respiratory unit, computer, and power source would be mounted to the soldier's backpack. Thermal control will be implemented at various locations throughout the system, therefore is not shown in Figure 2.

The respiratory protection unit would consist of an oxygen supply or oxygen generation module, connected to a translucent, form fitting mask (similar to RESPO 21 concepts). The mask would be integrated with close-fitting, impermeable hood. A sketch of the mask/hood configuration is shown in Figure 3. A rebreather-type system that employs oxygen generation from carbon dioxide (via electrolysis or chemical reaction with superoxides) would be recommended for maximum use of available oxygen sources. The supply and return breathing lines would be constructed of a rigid material and would be an integral part of the mask/hood arrangement, in order to prevent unnecessary damage (i.e. rupture) to the lines. A back-up filter should be designed into the system in the event of rebreather failure. Oxygen supply/generation will be needed for protection against unknown threats of the future. If filtration technologies keep up with modern warfare, then the respiratory concepts presented here can be replaced with filters.

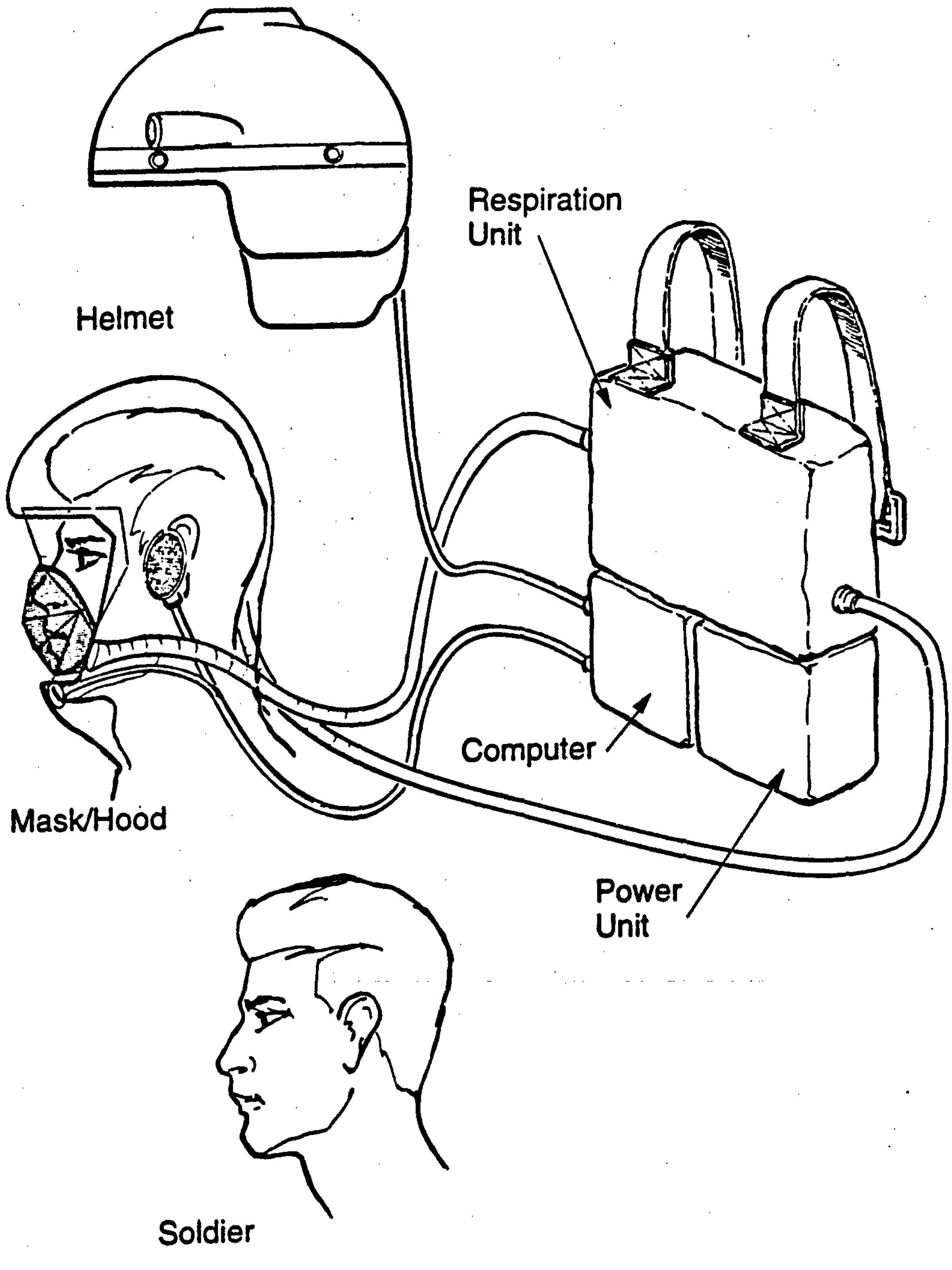

Figure 2. Sketch of AIPS Components

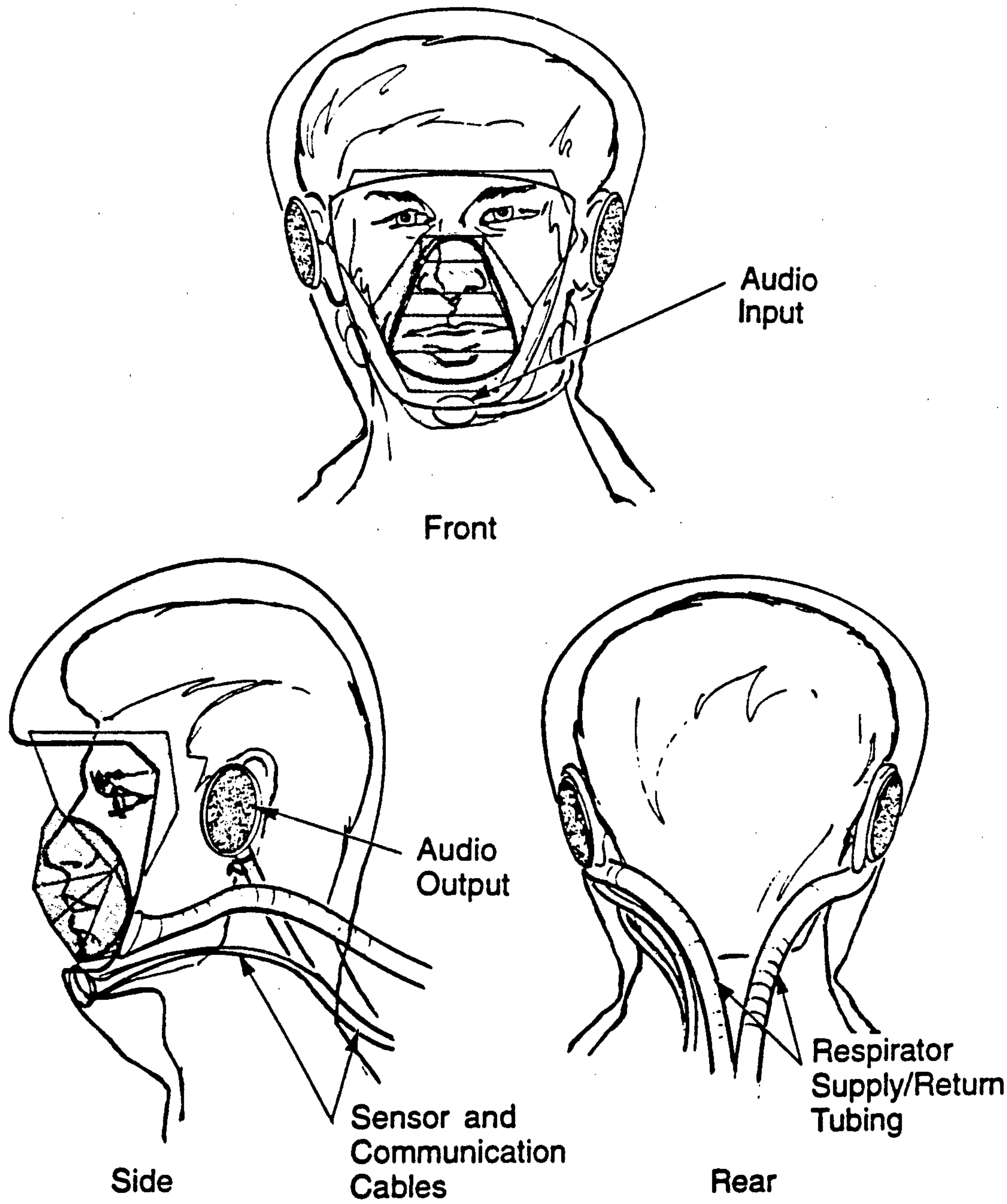

Figure 3. Sketch of Mask/Hood Concept

The mask/hood will include communication and sensor cables for integration with protective headgear. Electronics of the mask would include audio input/output (microphone/speaker), thermocouples for temperature measurement, pressure sensors for respiratory monitoring, and perhaps thermoelectric chips for cooling locations on the mask where heat build-up most often occurs. When the need for respiratory protection arises, the soldier will don his/her mask, then connect to their helmet, which will be the center of intelligence for the soldier.

The helmet will be used to improve a soldier's visual and auditory capabilities, while at the same time provide protection to the soldier's eyes and ears. An AIPS helmet would resemble a motorcycle helmet or fighter pilots helmet, versus helmets used by combat personnel today (see Figures 4 and 5). Current forms of enhanced vision (e.g. night vision goggles) and radio communications will be integrated into the protective headgear. With future advancements in microelectronics and reducing the size of computing power, more hardware can be incorporated into the liner/shell of the helmet.

As a future scenario could encompass several image sensors to provide visible light, infrared, and perhaps mm-wave radar images that would be processed by a flexible, teachable neural network computer and displayed on the inside of the AIPS visor. Although computer-generated, the image on the screen may be extremely realistic, and object identification may also be provided. This may be the soldier's main source of visual input, especially if future battlefield threat requires a totally encapsulated suit (sealed from head to toe). If threat permits use of a detachable helmet system, a shield over the visor could provide protection from flash, lasers, radiation, and projectiles.

The shield could be lifted to expose a translucent visor that partially protects the soldier's eyes and face, but allows for sight in case the computer is down, power is lost, or if the soldier is away from the combat site.

If optical input sensors were to malfunction, the wearer would need to rely on his own vision. A flip-type or retractable visor would be needed to disable the camera system and enable the natural vision system.

In the vision system above, a protective helmet face shield would be replaced with a computer screen, and the images projected upon that screen would be the images the cameras/optical sensors see. Thus the threat of blinding the soldier with lasers, bright light, or any other future threat would be eliminated, by electronically or optically filtering out potential hazards. In graphically re-creating a scene, several cameras would be needed to give the soldier depth perception. Currently, at least two cameras are needed to accomplish this. In the future, cameras could be mounted around the

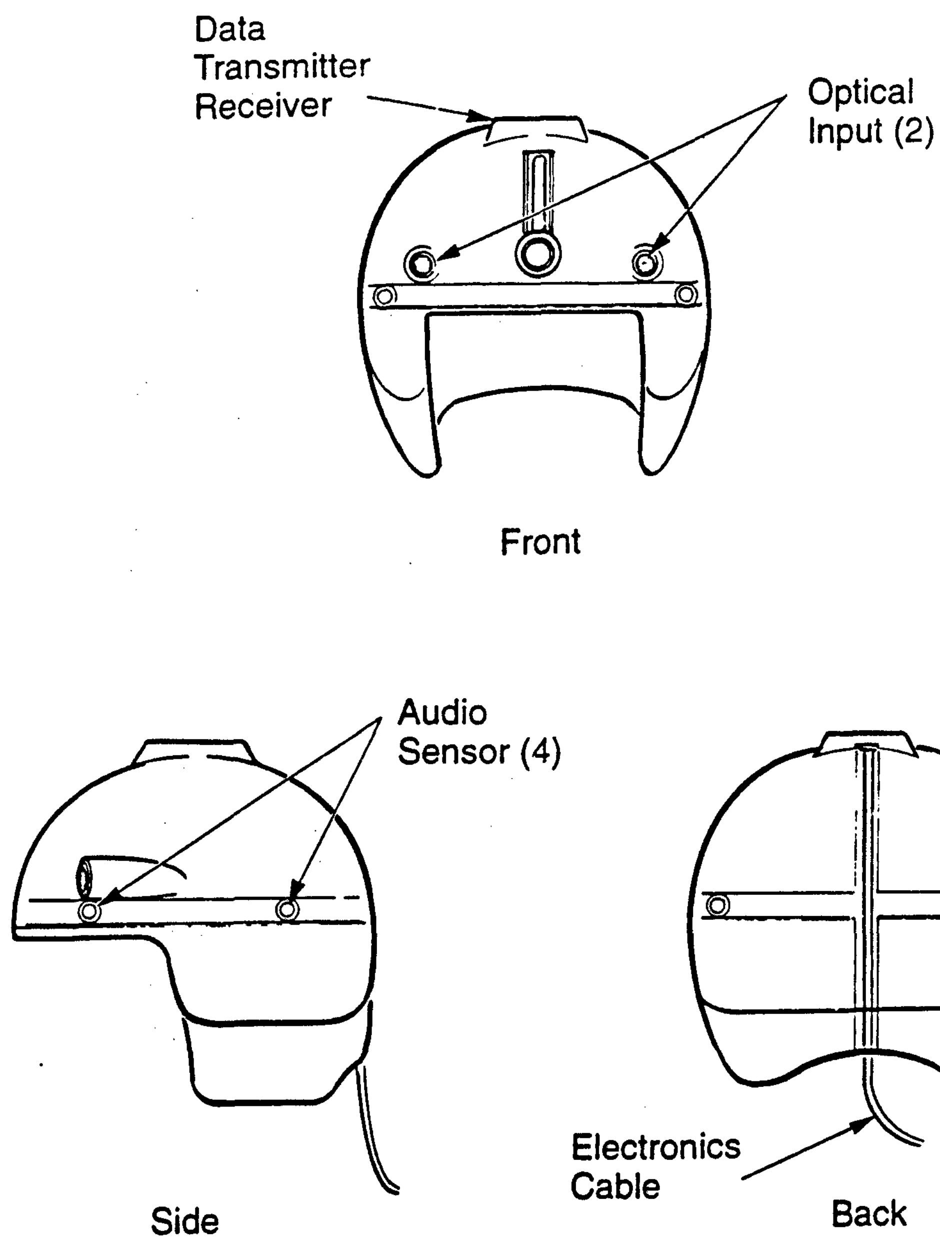

Figure 4. Sketch of Helmet Concept

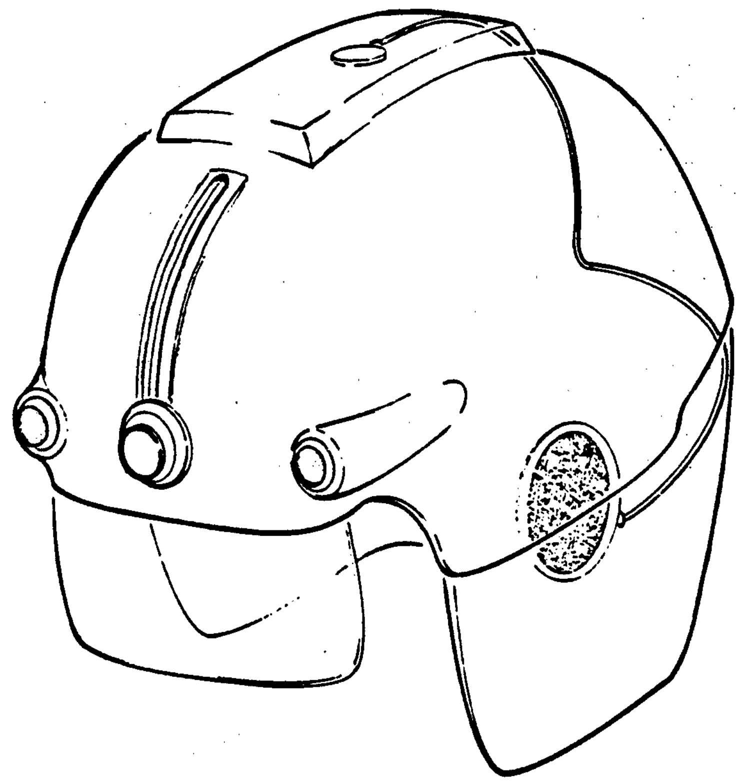

Figure 5. Helmet With Pull-Down Visor/Screen

helmet giving the soldier "eyes in the back of his head". The extra cameras could be employed to give a more realistic view as the wearer turns his head. As the head is turned left the computer anticipates this and starts tracking images using the cameras to the left so that no time is wasted waiting for the cameras to catch up. Also this possibility enables the user to actually get a "preview" of the view to the left than if he were using his natural vision. The addition of intelligent photosensors on the cameras in the back of the head would detect motion that the soldier was not looking directly at. Thus if a soldier was looking forward and there was movement behind him the intelligent photosensing system would realize this and transmit a message to the wearer, the wearer could then switch to an alternate camera. Processing speed right now makes this type of system impossible but anticipating real-time computing in the future makes this all the more probable.

Image enhancement and compression would be incorporated to help clarify all images received. Such a system would take each "frame of film" and visually enhance the unclear parts by comparing it to successive frames and eliminating the noise that can vary from frame to frame. This process at present is too slow to be practical but as the computing speed is increased the enhancement capabilities increase. A single frame image enhancing system might be of some use in an AIPS as a soldier could zoom in an area of interest and then let the computer take over. It could help to identify military vehicles, key personnel, etc. Image compression would allow such photos to be transmitted from one soldier to another or even back to base.

Regardless of the technology available in the future, a soldier will most often depend on his own eyesight rather than processed images that have been filtered for harmful effects. Thus, passive eye protection would have to be provided. A translucent visor shield would be made from material impermeable to lasers, as a glance at a laser could blind a soldier and render him handicapped. This system would be able to incorporate a limited form of heads-up display for displaying useful information to the soldier, such as possible enemy positions, mission messages from base, or a directional compass. The use of heads up display would have to be limited to the soldier's capability to process information. Overloading the soldier with unnecessary information or obstructing his field of view would reduce the efficiency in executing his mission. A retractable, scanning mirror display might be of some use here, as the soldier could access limited information from a small display as needed. Scanning mirrors can be used to display terrain maps, preview a current mission, show diagrams of enemy installations, or give detailed instructions on equipment repair. A scanning mirror could be incorporated underneath or just inside the soldier's visor. Some sort of automatic retraction

would be needed so that it could be removed from view when not in use. A possibility exists to retract it back into the helmet possibly by issuing a voice recognition command.

Voice recognition will enable the user to "speak" his commands and have the system respond to them. This will enhance his ability to do other things as he will not waste time fumbling around looking for knobs, buttons, etc. Problems such as being too hot or too cold could be corrected by simply telling the CPU that he is too hot. From there various systems would then kick in to rectify the situation. Voice recognition could also be used as a security measure. If an AIPS suit were to fall into enemy hands the information in it could be safe guarded by requiring the new user to have a voice print on file. Although this could probably be overridden it could serve as a safeguard by stalling the enemy trying to obtain the needed information. The main benefit though to voice recognition is it frees up the soldiers time to perform other tasks. In combat the extra second gained by voice recognition could mean the difference between success and failure.

Other auditory enhancements will also be made, one is binaural processing, which will simulate stereo and spatial sound inside the helmet. Wearing a close-fitting mask/helmet system causes discomfort to the soldier, as he is not really acting or reacting to the environment as he normally does. A helmet as such can make the wearer feel isolated and limits his interactions. The advancements in binaural processing might change this by enhancing the soldier's auditory capabilities. The soldier hears a three dimensional stereo sound, which would help him mesh with the environment much better. Hearing sensors for binaural processing could be used as magnifiers and filters, magnifying the inaudible sounds and filtering out unwanted background noises such as a running engine. Such a system could be extremely sensitive to noise levels. An explosion could be filtered out to protect and preserve the users hearing while low level noises could be amplified to enhance the users hearing.

Different types of outgoing communication that could be incorporated into AIPS are being developed. Laser communications provide a more secure transmission of data compared to current radio frequency transmission. A small laser would be mounted above the soldiers head could provide line of sight communications Current methods of communication have broad signal transmissions, which are easy to intercept when compared to a laser system with a signal only as thick as a laser, which is directed to one specific point. Advancements in laser communications could enable

information to be transmitted to a soldier from halfway around the world via satellites. Wireless LAN's could also be incorporated here, however, current technology would be limited to soldier to soldier communication. Hard-to-detects LAN's could be designed, but are only practical for short distances. Both systems offer greater security than communication systems of today.

Some of these technologies may seem far-fetched but with the advancements in computing technology, they are all very possible in the future. Projecting current technology thirty years into the future is a highly uncertain task. Yet current technology research can be used as a springboard for idealistic visions. Such "dreams" may not be realistic, but they may serve as goals to work toward and as such are extremely valuable at the very early stages of system development.

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10. The Army Technology Base Master Plan (ATBMP).

ABBREVIATIONS/ACRONYMS

AIPS	Advanced Individual Protection System
ANP	analog nueroprocessors
ANVIS	Aviators Night Vision Imaging System
ARDEC	Armament Research Development Engineering Center
ATD	Advanced Technology Demonstration
ATD	Aided Target Detection
BRDEC	Belvoir Research Development Engineering Center
CBIAC	Chemical Warfare/Chemical and Biological Defense Information Analysis Center
CCD	liquid crystal display
CCD	charged coupled device
CECOM	Communications and Electroncis Command
CELSS	Closed (or Controlled) Ecological Life Support System
CPU	computer processing unit
CRT	cathode ray tube
CVC	combat vehicle crew
DARPA	Defense Advanced Research Project Agency
DTIC	Defense Technical Information Center
ERDEC	Edgewood Research Development Engineering Center
FGA	Front End Analysis
HMD	helmet mounted display
HUD	heads up display
IAD	interaural amplitude difference
IMCS	Individual Microclimate Cooling System
IPE	Individual Protection Equipment
ISD	interaural spectral difference
ITD	interaural time difference
LAN	local area network
LDC	liquid crystal display
LED	light emitting diode
NASA	National Aeronautics and Space Administration
NRDEC	Natick Research Development Engineering Center
NVG	night vision goggles
OCR	optical character recognition
PCM	phase change materials
POC	point of contact
RESPO 21	Respiratory Protection System 21
RF	radio frequency
SCBA	self contained breathing apparatus
SIPE	Soldier Integrated Protective Ensemble
STEPO	Self-Controlled Toxicological Environmental Protection Outfit
TACTEC	Tactical Technology Center
TE	thermoelectricity
TEISS	The Enhanced Individual Soldier System
UBA	underwater breathing apparatus
VLSI	very large scale integration
VR	virtual reality
WVA	water vapor electrolysis

APPENDIX A

POINTS OF CONTACT LISTING

TECHNOLOGY COMMUNITY CONTACTS

Organization	Name	Phone	Comments
Armstrong Aerospace Medical Research Laboratory WPAFB, OH 45433	Gloria Calhoun	513-255-3856	Working on brain actuated control. Had worked on eye controls. Provided some info and additional POC's.
	Dr. Charles W. Nixon	513-255-3607	Provided info on 3-D audio systems and IR systems.
	Patricia Lewandowski	513-255-2125	AAMRL Information Office. Provided POC's.
Advanced Technology Program National Institute of Standards & Technology, Gaithersburg, MD 20899	Bill Nelson Mike Stogsdill	301-975-3105 301-975-2365	Sent info on type of work they fund, not much related.
Armament Research, Development and Engineering SMCAR-AST Picatinny Arsenal, NJ 07806-5000	Peter Rowland, Dutch Meier	201-724-6365	Peter Rowland ("Man Magnifier" article). Meier referred us to NRDEC as overall manager of Man Magnifier. They do work on fire control, target acquisition.
	Robert Zanowicz	201-724-6979 (fax) x4111	Armaments, Fire Control, Optics for. Offered to review info and pass on. Provided no additional information.
Center for Electronics and Electrical Engineering National Institute of Standards & Technology, Gaithersburg, MD 20899	Judson C. French	301-975-2220	R&D of electronics, electrical materials, devices, instruments, and systems. Referred to Advanced Technology Program.
Defense Advanced Research Project Agency (DARPA)	Dick Urban	703-696-2203	LCD heads-up displays.

Organization	Name	Phone	Comments
Department of Rehabilitation Research and Development Center Hines VA Hospital, PO Box 20, Hines, IL 60141	Dr. John Trimble	708-216-2240 fax-708-531-7928	Basic and applied research and product development of biomaterials, medical instrumentation, electronic aids, voice-op controls, human factors, and biomechanics. Provided information and hosted visit to discuss these technologies.
Electronics Technology and Devices Laboratory Army Laboratory Command (LABCOM) Attn: SLCET-DT, Monmouth, NJ 07703	Richard A. Stern	908-544-4666	Develop and upgrade devices to support the next generation of Army combat systems. No new information.
Federal Laboratory Consortium 224 W. Washington, Ste #3 P.O. Box 545 Sequim, WA 98302	Lisa Perry	206-683-1005 fax-206-683-6654	Conducted searches at Federal Lab Locator Service. Provided additional POCs.
Great Lakes Technology Transfer Center 25000 Great Northern Corporate Center, Suite 450 Cleveland, OH 44070-5310	Dr. Joe Ray	216-734-0094 fax-216-734-0686	Conducted literature searches of NASA databases.
Hamilton Standard Connecticut	Mike Puskar Jim McElroy	203-654-6000 203-654-3427	Developed water electrolysis system for NASA Marshall Space Center (4-man space station unit).
Harry Diamond Laboratories, DA 2800 Powder Mill Rd Adelphi, MD 20783-2520	John Pellegrino	301-394-2520 fax-301-394-4214	Provided information on sensors, signals, and information processing. R&D includes acoustic and electro optics, neural networks, and holographic processing. Provided information.

Organization	Name	Phone	Comments
Human Interface Technology Lab University of Washington; Seattle, WA	Tom Furness	206-543-5075	Virtual Reality - from G. Calhoun Used to be at WPAFB.
Idaho National Engineering Laboratory (DOE) PO Box 1625, Idaho Falls, ID 83415	Dr. Jane Gibson Steve Bryan	208-525-5450 208-525-5484	Information sent on computer based prototype electronic and electrical systems; integration of hardware and software. Steve is working on speech processing neural networks.
Information Technology Laboratory Army Engineer Waterways Experiment Station, PO Box 631, Vicksburg, MS 39181-0631	Philip Stewart	601-634-4113	R&D in the information technology areas of computer science; automation; voice, video, data, and satellite communications; audiovisuals, and interdisciplinary engineering computer areas.
Institute for Telecommunication Sciences NTIA, Boulder, CO 80303	Val M. O'Day	303-497-3484 fax-303-497-5993	Research on the efficient use of the RF spectrum, engineering and evaluation of communication systems and propagation and transmission of radio signals. No information provided.
Life Systems, Inc. Cleveland, OH	Dr. Gene Lee	216-464-3291	Developed 3-person water vapor electrolysis unit for NASA LBJ Space Center in 1988. No further work on WVE. Have proposed space backpack water electrolysis unit for oxygen/hydrogen generation.
Los Alamos National Lab Advanced Weapons Technology Group	Jeff Moore	505-665-5300	Assisted in preparation of "Man Magnifier" article. Pitman (exoskeleton project). Mostly robotics, exoskeleton. No information provided.
Marlow Industries Inc.	Peter Lyman	214-340-4900	Manufacturer of thermoelectric cooling devices.
Melcor / Materials Electronic Products	Milton Levine	609-393-4178	Manufacturer of thermoelectric cooling devices.

Organization	Name	Phone	Comments
Microstructure Laboratory (Brookhaven National Laboratory) Instrumentation Division, 535-B, Upton, NY 11973	John Warren	516-282-4203 (fax)516-282-5773	Design and manufacture microstructural components (micromachining). In the future, he will be helpful in assessing the feasibility of bringing "macro" systems down to the individual level. Information received. Fabrications for integrated circuits.
NASA Ames Research Center Flight Systems and Simulation Division Moffett Field CA 94034 (San Jose)	Dallas Denery	415-604-5427	Navigation/flight controls; helmet displays.
NASA Audio Systems Laboratory NASA LBJ Space Center Houston, TX 77058		713-483-2873 713-483-5111	Headset, earphones, microphones, voice processing units, space-suit communication systems. Apparently not in business any more. Eventually referred to Boeing.
NASA Portable Life Support Systems Lyndon B. Johnson Space Center	Mike Lawson	713-483-9124	Provided information in high pressure oxygen storage and developmental cryogenic technologies. Provided additional POC's.
NASA Propellant Handling	Cole Bryan	407-867-4344	User of conventional breathing apparatuses. Oxygen tanks, compatibility, oxygen intake. "LIQ-AIR" Pack.
NASA Space and Engineering Research Center	Dr. Kumar Ramohalli	602-621-2395	Provided info on CO_2 electrolysis for Martian application. Beginning experiments introducing H_2O vapor, nitrogen.

Organization	Name	Phone	Comments
Naval Submarine Medical Research Laboratory Naval Medical R&D Command, Submarine Base, New London Groton, CT 06349-5900	Dr. Kevin Laxar Art Callahan	203-449-2522 203-449-4809 203-449-2539	Optics/vision department. Provided information. -- conspicuity (signal lights vs onshore lights) -- sonar research - identifying stimuli on sonar displays -- color coding - navigational tactical displays
Naval Aerospace Medical Research Laboratory Code 00B2 Naval Air Station Pensacola, FL 32508	Kathleen Mayer	904-452-3686	R&D and T&E in aviation medicine and allied sciences to enhance the health, safety and performance of Marine Corps and Navy personnel.
Naval Center for Applied Research in Artificial Intelligence Naval Research Laboratory Washington, DC 20735	Dr. George Abraham	202-767-3521	Artificial intelligence applications, future plans include robotics. -- electron devices -- human - computer interaction group -- battle management -- artificial intelligence
Pacific Northwest Laboratories	Dr. Loren Schmid	509-375-2559	Chairman, Federal Lab Consortium. Referred to lab locator service.
Sandia National Laboratory DOE Technology Transfer & Policy Dept., PO Box 5800 Albuquerque, NM 87185	Dan Arvizu	505-846-0387	Involved in specialized microelectronics R&D.
Sphinx Technologies	John Sangster	617-235-8801	Communications, Respiratory Tests
TE Technology Inc.	Richard Buist	616-929-3966	Manufacturer of thermoelectric cooling devices.

Organization	Name	Phone	Comments
Tellurex Corp.	Greg Smith	616-947-0110	New small company. Very interested in getting involved with Army projects - contact for further information. Manufacture hi-temp, study TE devices.
Thermoelectric Cooling America Corp.	Daniel Cusick	312-666-1600	Manufacturer of thermoelectric cooling devices.
University of Arizona Aerospace and Mechanical Engineering Department	Dr. K.R. Sridhar	602-621-6111	Oxygen generation from CO_2 electrolysis.
University of Dayton Dayton, OH	Ival Salyer	513-229-2113	Phase change materials.
Wright Laboratory XPT(ORTA) WPAFB, OH 45433-6523	William Anderson	513-255-8997	Expertise in electro-optics, sensor environmental evaluation, radar systems, avionic systems, guidance controls.

OTHER TECHNOLOGY POC's (not contacted)

Organization	Name	Phone Number	Comments
Army Office of Research			
Army Combat Systems Test Activity	Cpt Jim Berry	410-278-8645	Robotics testing; demonstration, sensor technologies, mobility, accuracy
Communications and Electronics Command (CECOM)	Jim Wright	908-544-2819	SIPE Communications
FMC Corporation	John Morrow		Assisted in preparation of "Man Magnifier" article.
Human Engineering Laboratory 2800 Powder Mill Rd Adelphi, MD 20783	Peter Paicopolis	508-651-5517	Human factors testing
LABCOM	Dennis Manyak	410-394-3160	"Subject Matter Expert" for LABCOM's Survivability Management Office (SMC)
NRDEC	Robert Rosenkrans	508-651-5296	Individual Protection Directorate
NRDEC	Carol J. Fitzgerald	508-651-5436	SIPE
NRDEC	Pio Angelini		Reactive Materials
PM-Soldier	Chuck Giddley	703-490-2406	The Enhanced Integrated Soldier System (TEISS)
NASA - Ames Research Center	Dave McNally Dr. Ralph Bach	415-604-5440 415-604-5429	GPS Carrier Phase Tracking -- allows foot solider to navigate in poor visibility

Organization	Name	Phone Number	Comments
NASA - Ames Research Center	Dr. Banavar Sridhar	415-604-5450	IR & MMW Cameras – image processing
Wright-Patterson AFB	Scott Hall	513-255-8895	Augmented Sensor Program, Helmet System Mounted Technology Office
	Dr. Lee Task	513-255-8816	Night vision system
	Dave Hoagland	513-255-8719	F-16 SPO
US ARIEM	William Prusaczyk	508-651-5142	RESPO 21 Design Workshop
USAIS	Maj. Charlie Pavlick	404-835-3087	Infantry School

BATTELLE CONTACTS

Name	Phone	Area of Interest
Kathy Alexander	614-424-6467	Miscellaneous IPE background in plastics
Dave Bennett	509-375-2159	"Manny" the mannequin (robotics, sensors, etc.)
Gene Brawley	614-424-4581	Neural networks
Mark Byrne	614-424-5847	RESPO 21 - Breathing Assistance, Communications (Noise Canceling), Physiological Sensors
Tim Carpenter	614-424-5904	RESPO 21 - Lightweight Protective Mask
John Chovan	614-424-3208	Human Factors
Barb Fecht	509-376-0929	"Manny" the mannequin (robotics, sensors, etc.)
John Garvey	614-424-7507	Electro-optics (deferred to Smith, Walters, Stockum)
Terry Hill	614-424-4453	Thermal, Future Fighting System
Ken Hughes	614-424-7627	Medical Technologies
Joseph Jacomet	614-424-6533	Polymer Science, Aerogel (referred to Holbrook)
Ed Kopala	614-424-4992	Optics
Mike Kuhlman	614-424-5393	RESPO 21 - Carbon Technology
Mark Kuhner	614-424-7314	Notional Individual Fighting System (Data Transmission and Communications)
John Kurmer	614-424-5725	Laser Protection
Eugene Leach	614-424-5675	Notional Individual Fighting System (Holographic Displays, MW); Electro-optics and displays
Ruth Linebaugh	614-424-7880	Diver Equipment - Artificial Gill, Rebreathers
Jan Milosh	614-424-4656	Miscellaneous IPE
Mike Milosh	614-424-7868	Notional Individual Fighting System (Life Support Systems, Structures)
Lou Myers	614-424-7166	Human Factors
Tom Pettenski	614-424-7825	RESPO 21 - Multilayer Mask; Master Control Unit
Tammy Ramirez	513-258-6721	Human Factors, Thermal Stress
Pete Riegel	614-424-4009	SCBA (has not done much with this lately)
George Ruck	614-424-5685	Microwave Transmitters and Receivers

Name	Phone	Area of Interest
Arthur Schultz	614-424-5479	Notional Individual Fighting System (Life Support Systems, Structures)
Milt Seiler	614-424-5684	Microwave Transmitters and Receivers
Dr. B. Tom Smith	614-424-5745	Electro-optics
Larry Stockum	614-424-3217	Optics/Communications
Louis Tijerina	614-424-5406	Human Factors
Bernard Tullington	703-516-7453	Notional Individual Fighting System (Project Leader)
Craig Walters	614-424-3160	Optics/Communications
Ken Woodruff	614-424-4091	RESPO 21 Breathing Assistance

APPENDIX B

DATABASE DESCRIPTIONS

INSPEC (Information Services for the Physics and Engineering Communities)

Type: Bibliographic

Subject: Computer Science; Electronics; Engineering; Library & Information Science; Physics

Producer: Institution of Electrical Engineers (IEE)

Content: Contains more than 4 million citations, with abstracts, to the worldwide literature in physics, electronics and electrical engineering, computers and control, and information technology. Primary coverage is of journal articles and papers presented at conferences, although significant books, technical reports, and dissertations are also included.

Topics covered in physics include: mathematical and theoretical physics; electromagnetism and optics; quantum field theory and elementary particle physics; nuclear physics; atomic and molecular physics; gases, fluid dynamics, and plasmas; structural, thermal, mechanical, electrical, magnetic, and optical properties of condensed matter; acoustics; geophysics; astronomy and astrophysics; instrumentation and measurement; and related interdisciplinary topics.

Topics covered in electronics and electrical engineering include: circuits and components; electron devices and materials; electromagnetics and communication; energy and power systems and applications; and telecommunications.

Topics covered in computers and control include: systems and control theory; control technology; computer programming and applications; and computer systems and equipment. Information technology topics include applications of modern communications and computing to the production, transmission, storage, and interpretation of visual, oral, and digitally encoded information. Hardware coverage includes microcomputers and related peripherals. Corresponds to these publications: Physics Abstracts, Electrical and Electronics Abstracts, and Computer and Control Abstracts.

Coverage: International

Compendex (Computerized Engineering Index)

Type: Bibliographic

Subject: Engineering

Producer: Engineering Information, Inc. (Ei)

Content: Contains more than 2.5 million citations, with abstracts, to the worldwide literature (excluding patents) in engineering and technology. Fields of engineering include: civil, water and waterworks, sanitary and waste, fuel, bioengineering geology and mining, petroleum, metallurgical, mechanical, industrial, aerospace, automotive, marine,

railroad, electrical, electronics and communications control, chemical, and agricultural. Related subject areas covered include construction materials, properties and testing of materials, transportation, pollution, ocean and underwater technology, nuclear technology, fluid flow, heat and thermodynamics, computers and data processing, light and optical technology, sound and acoustical technology, food technology, applied physics, instruments, measurements, and information science. Conference review records contain conference code numbers which are links to complete coverage of all individual papers in Ei Engineering Meetings. Corresponds to The Engineering Index Monthly and The Engineering Index Annual.

Coverage: International

NIOSHTIC (Alternative Name: NIOSH Technical Information Center Database)

Type: Bibliographic

Subject: Occupational Safety & Health

Producer: U.S. National Institute for Occupational Safety and Health (NIOSH), Standards Development and Technology Transfer Division, Technical Information Branch (TIB)

Content: Contains more than 169,000 citations, with abstracts, to literature on occupational safety and health from more than 150 core journals, as well as monographs and technical reports. Covers toxicology, epidemiology, pathology, occupational medicine, health physics, injury prevention, ergonomics, biochemistry, physiology and metabolism, industrial hygiene, safety, processes and materials in the work place, behavioral sciences, education and training, control technology, biological hazards, and hazardous waste. Includes Chemical Abstracts Service (CAS) Registry Numbers.

Coverage: International

Microcomputer Index

Type: Bibliographic

Subject: Computers & Computer Industry; Computer Uses & Users

Producer: Learned Information, Inc.

Content: Contains approximately 131,000 citations, with abstracts, to reviews and commentaries on the use and applications of microcomputers and software packages. Covers more than 70 microcomputer journals and popular magazines, including Byte, Practical Computering, InfoWorld, Personal Computing, MacWorld, and PC World. Includes summaries of general articles about microcomputers, book reviews, software and hardware reviews, and specifications for individual packages, discussions of applications in various settings, and descriptions of new microcomputer hardware and software

products. Also provides the complete text book reviews of computer titles from Computer Book Review, and price comparison information on popular software packages from Softwhere? Bargains Report. Corresponds to the quarterly Microcomputer Index.

Coverage: Australia, United Kingdom and United States

Robotics (Alternate Name: Robotics Abstracts; Former Name: Robomatix Online)

Type: Bibliographic

Subject: Manufacturing Systems & Technologies; Robotics

Producer: Bowker A & I Publishing

Content: Contains more than 12,800 citations, with abstracts, to the worldwide published and unpublished literature dealing with the business, marketing, research, and policy and regulatory aspects of robotics. Applications in manufacturing, aerospace, agriculture, education, and the home are covered, including those dealing with artificial intelligence, casting, computer-aided design/computer-aided manufacturing (CAD/CAM), inspection and optical systems, locomotion, materials handling, mechanical design, product assembly, prosthetics, and sensors. Also contains the complete text of one article per update on the industry's most significant news, trend, or achievement. Sources include journals, conference proceedings, market-forecast studies, corporate- and university-issued reports, news stories, press releases, and U.S. Congressional hearings. Corresponds to Robotics Abstracts.

Coverage: International

Artificial Intelligence

Type: Bibliographic

Subject: Computer Science, Biotechnology

Producer: Bowker A & I Publishing

Content: Provides references and abstracts of the world's published literature relating to the theoretical and applied aspects of artificial intelligence.

Coverage: International

Health and Safety Science Abstracts (HSSA)

Type: Bibliographic

Subject: Occupational Safety & Health; Safety

Producer: Cambridge Scientific Abstracts (CSA)

Content: Contains approximately 64,000 citations to the worldwide literature on safety science and hazard control, with an emphasis on the identification, evaluation, and elimination or control of hazards. Covers industrial and occupational safety, transportation safety, aviation and aerospace safety, environmental and ecological safety, and medical safety. Includes such topics as environmental pollution and waste disposal, radiation, pesticides, natural disasters, toxicology, genetics, epidemics, drugs, injuries, diseases, and criminal acts (e.g., arson). Also covers issues related to liability. Sources include books, periodicals, government reports, conference proceedings, patents, and dissertations. Corresponds to Health and Safety Science Abstracts.

Coverage: International

World Patents Index (WPI)

Type: Bibliographic

Subject: Patents

Producer: Derwent Publications Ltd.

Content: Contains more than 5 million citations, with abstracts, to chemical, electrical, mechanical, and general patents issued by 31 major patent-issuing authorities. Data elements include title; patent assignee and inventor name; patent numbers; World Intellectual Property Organization (WIPO) member country; priority and publication dates; and various classification and subject codes. Corresponds to coverage in the abstracts publications, Chemical Patents Index (CPI), General & Mechanical Patents Index (GMPI), and Electrical Patents Index (EPI).

Coverage: International

APPENDIX C

REFERENCES FOR TECHNOLOGY DESCRIPTIONS

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R4. Mausteller, J.W. "The characterization of carbon dioxide adsorbing agents for life support equipments", taken from Proceedings of the Winter Annual Meeting, American Society of Mechanical Engineers, 1982, p23-31.

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R6. Riegel, P.S. and J.M. Milosh "Self-Contained Breathing Apparatus for Field Use", Battelle Columbus Laboratories, August 30, 1985.

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T4. Speckman, Karen L., et. al., "Perspectives in Microclimate Cooling Involving Protective Clothing in Hot Environments," International Journal of Industrial Ergonomics, v 3, n 2, December 1988, pp121-147.

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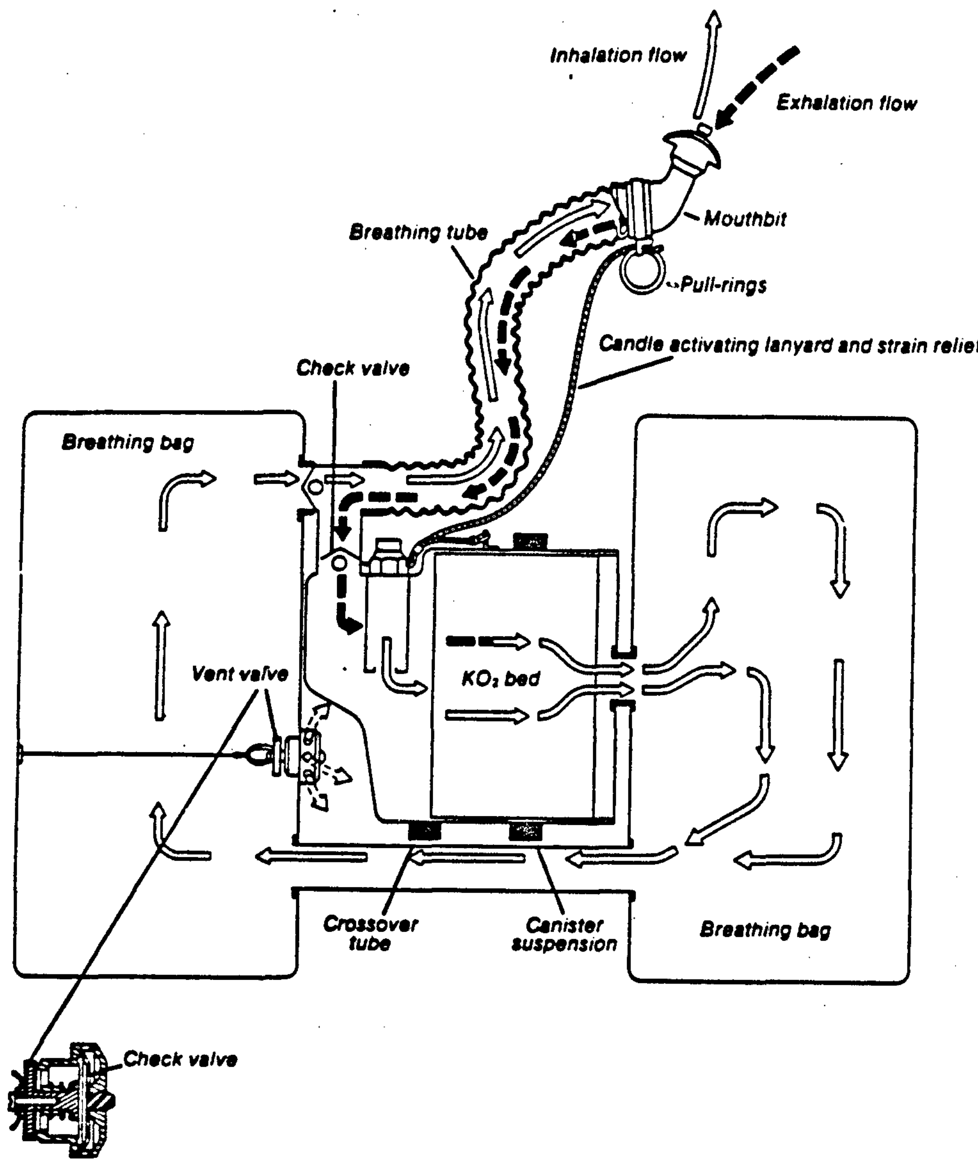
APPENDIX D

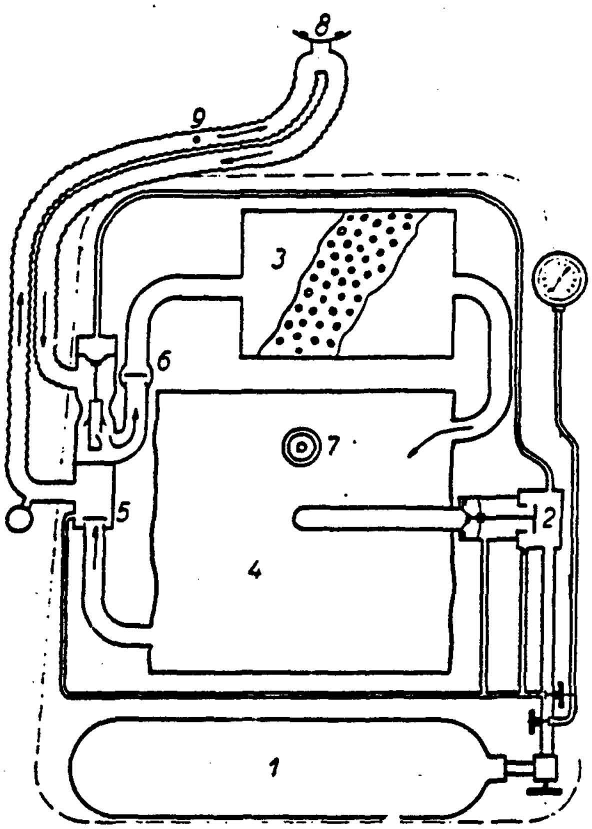
FIGURES FOR TECHNOLOGY DESCRIPTIONS

APPENDIX D

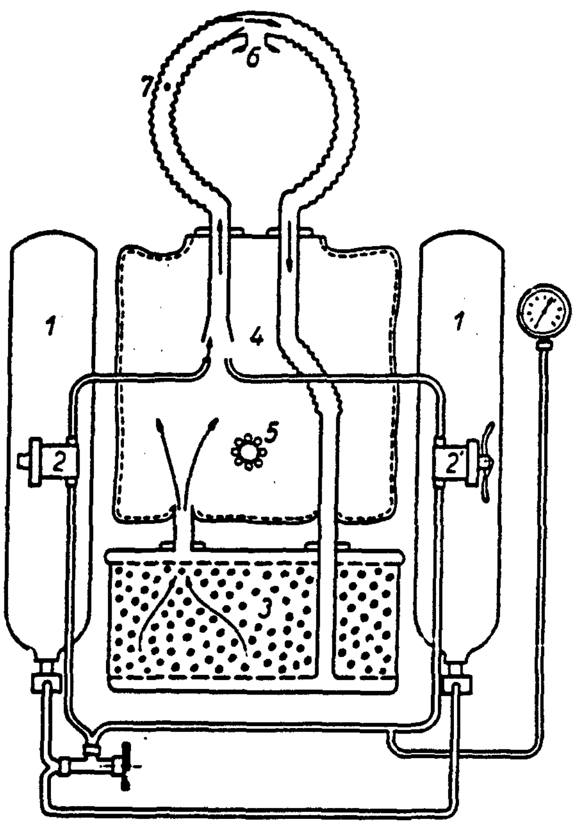
FIGURES FOR TECHNOLOGY DESCRIPTIONS



D-1. Schematic of a Chemical Oxygen Rebreather

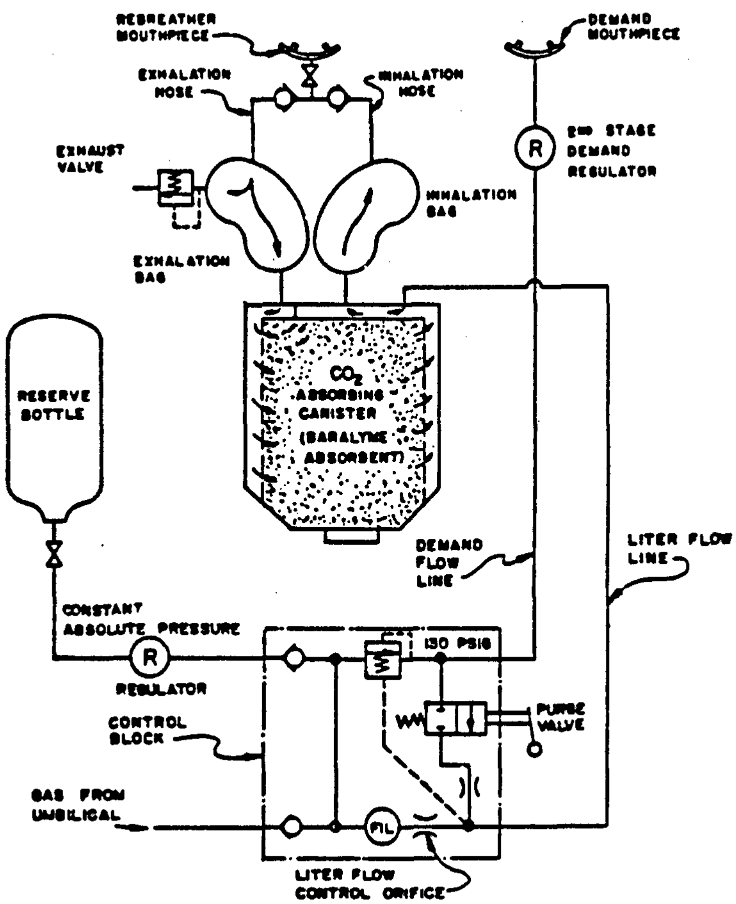


(1) Compressed oxygen cylinder. (2) Pressure reducer and controlled oxygen supply. (3) Carbon dioxide absorber (caustic potash). (4) Breathing bag. (5) Inhalation valve. (6) Exhalation valve. (7) Relief valve. (8) Mouthpiece. (9) Thermocouple.

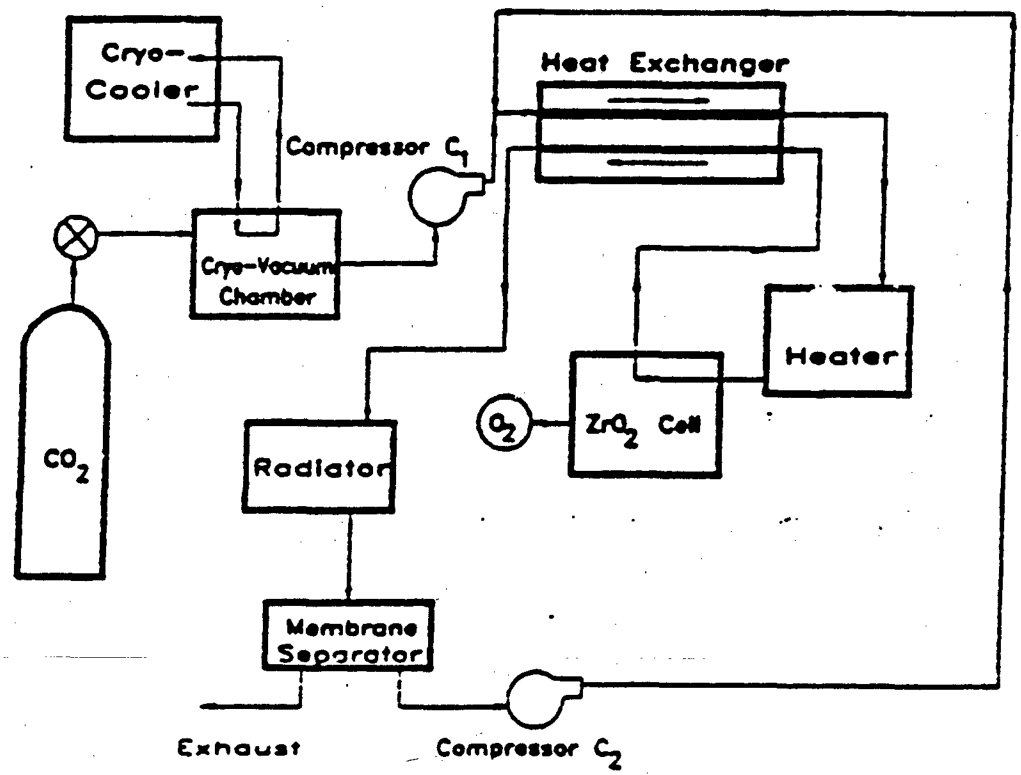


(1) Compressed oxygen cylinders. (2) Pressure reducer. (2') Reserve pressure reducer. (3) Carbon dioxide absorber (soda-lime). (4) Breathing bag. (5) Relief valve. (6) Mouthpiece. (7) Thermocouple.

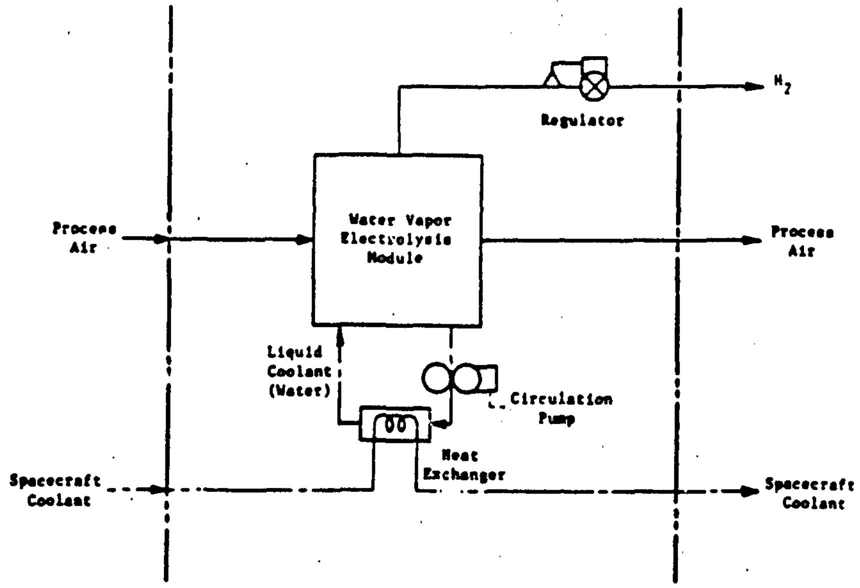
D-2. Schematics of Closed-Circuit Compressed Oxygen Rebreathers



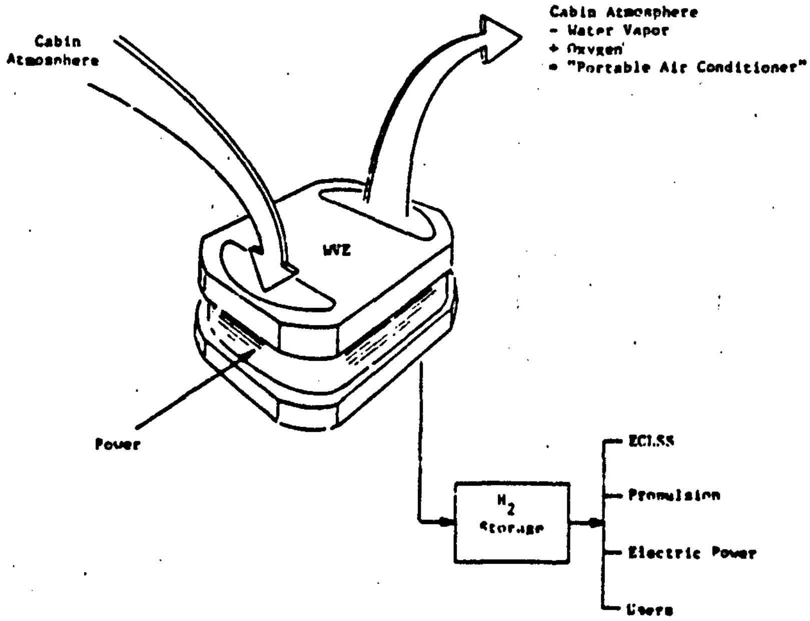
D-3. Schematic of a Semi-closed Circuit SCBA



D-4. Schematic of an Oxygen Generating Plants for Mars

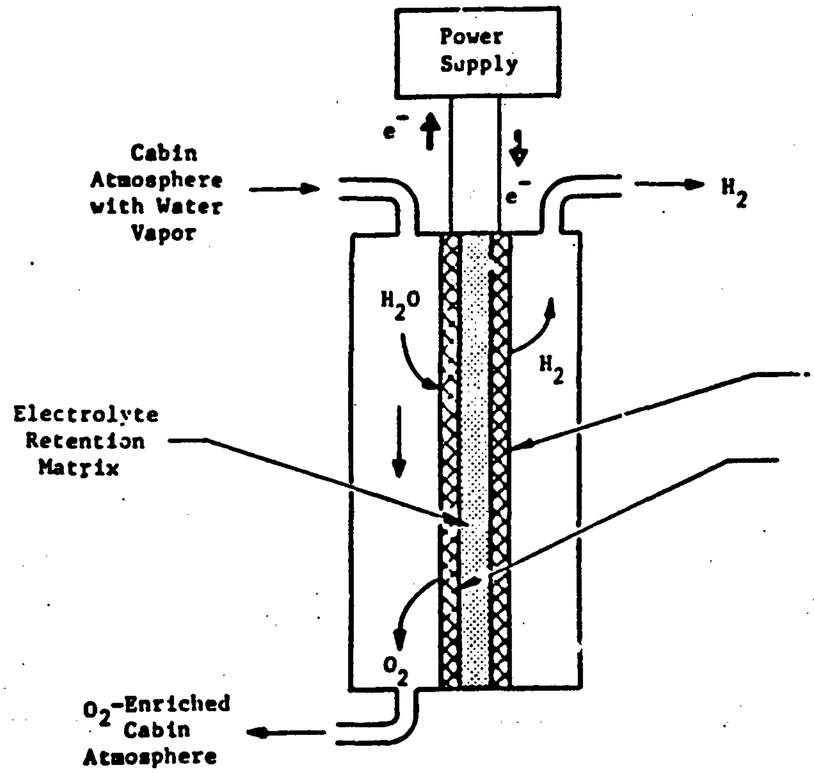


Functional Schematic



Spacecraft Application

D-5. Water Vapor Electrolysis Concept (for spacecraft)

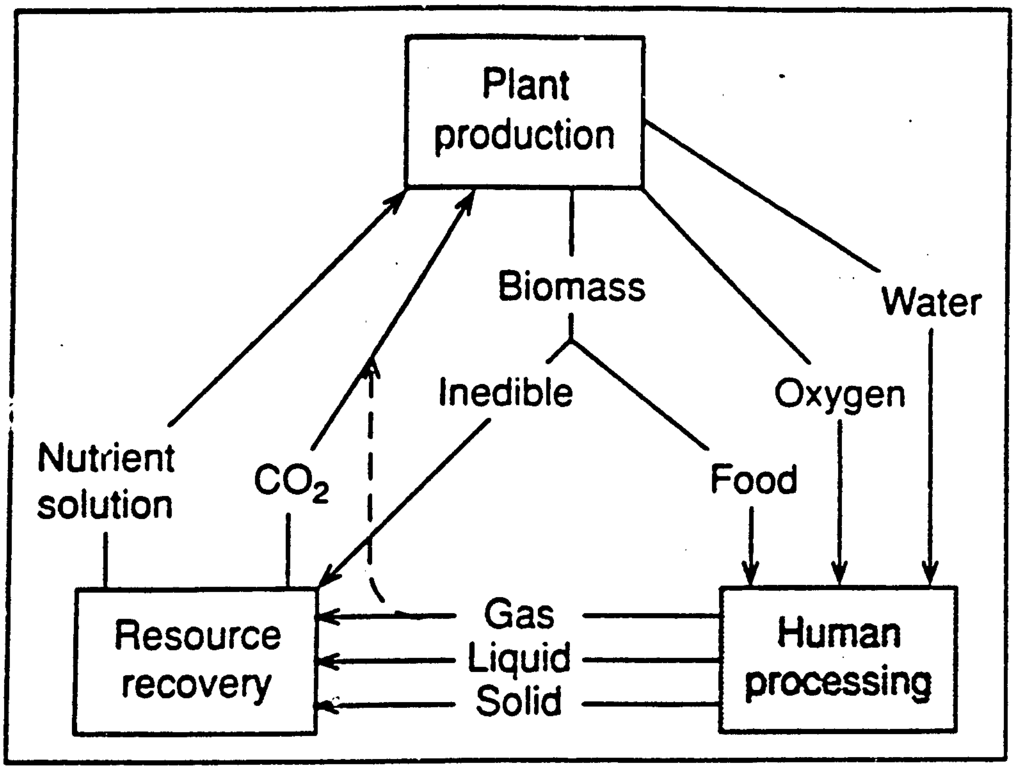


Cathode: $4H^+ + 4e^- = 2H_2$

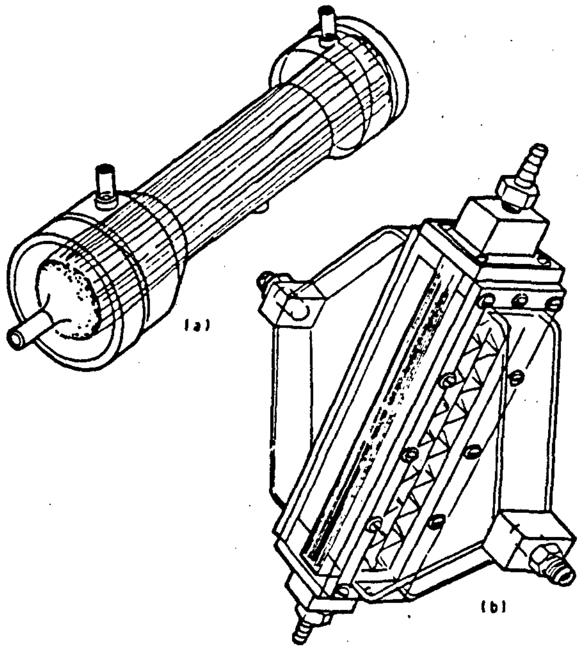
Anode: $2H_2O = O_2 + 4H^+ + 4e^-$

Overall: $2H_2O$ + Electrical Energy $\rightarrow 2H_2 + O_2$ + Heat

D-6. Schematic of WVE Cell and Reactions



D-7. Schematic of a Controlled Ecological Life Support System (CELLS)



Artificial gills. Both types are based on microporous hollow fibers. In unit (a) on the left, water flow is parallel to the fibers; in unit (b) on the right, it is perpendicular.

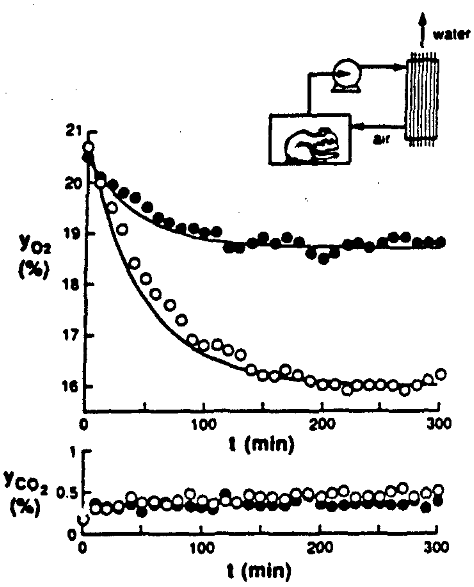
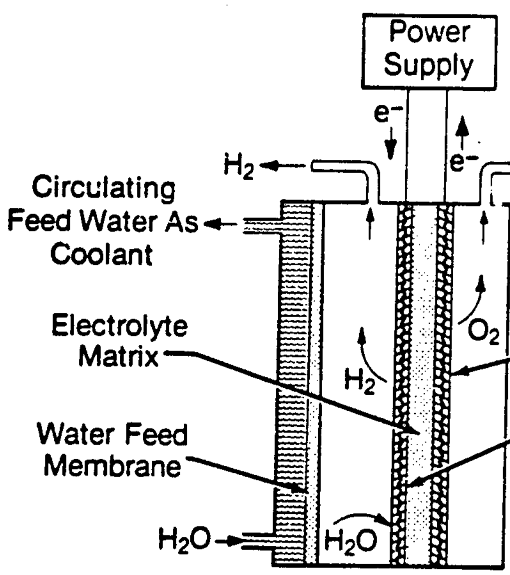


Fig Hamsters breathing with an artificial gill. The changes in oxygen concentration are due to hamster breathing. Solid points and open points are for parallel flow and cross flow modules, respectively. The solid lines are not fits of the data, but theoretical prediction of gill performance.

D-8. Artificial Gills



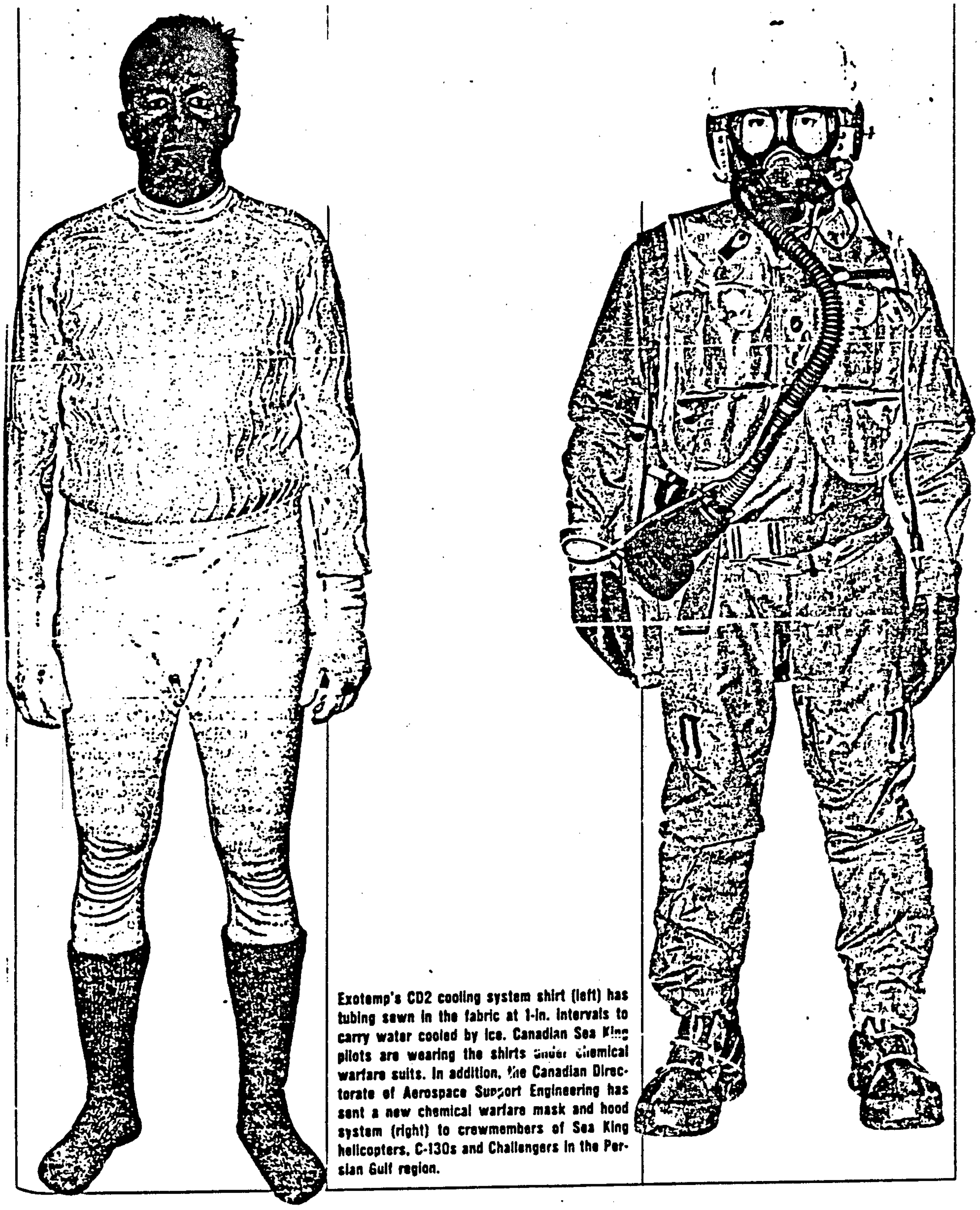
Reactions

Anode (+): $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$

Cathode (-): $4H_2O + 4e^- \rightarrow 2H_2 + 4OH^-$

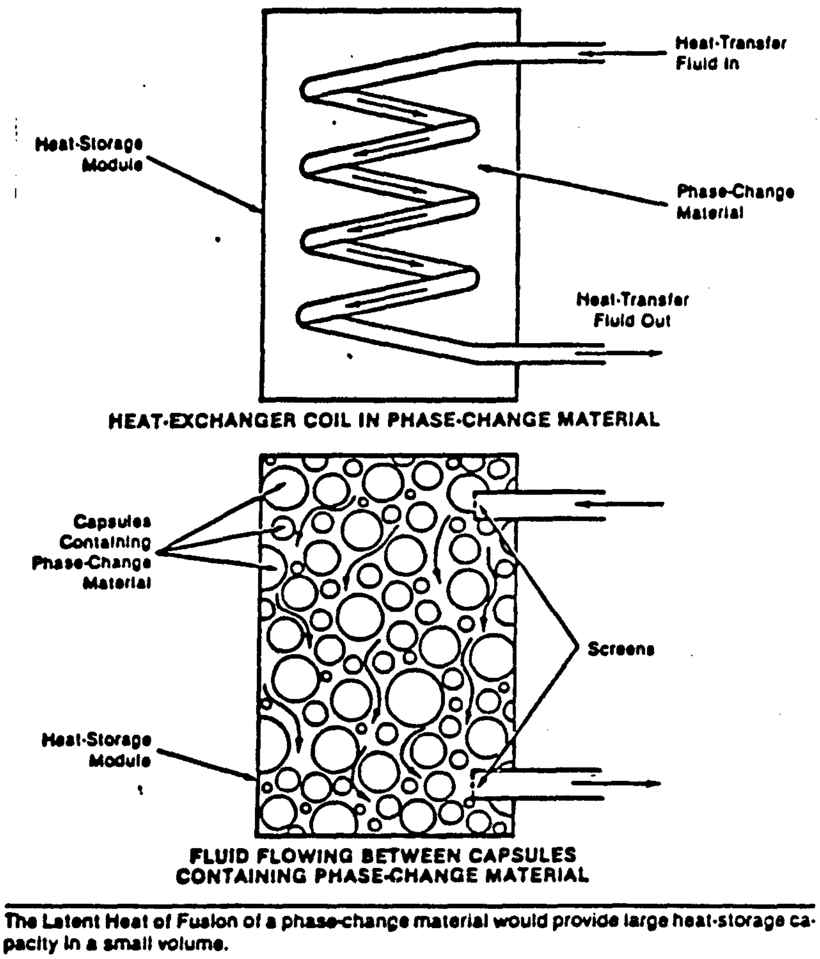
Overall: $2H_2O \rightarrow 2H_2 + O_2$

D-9. Water Electrolysis Process

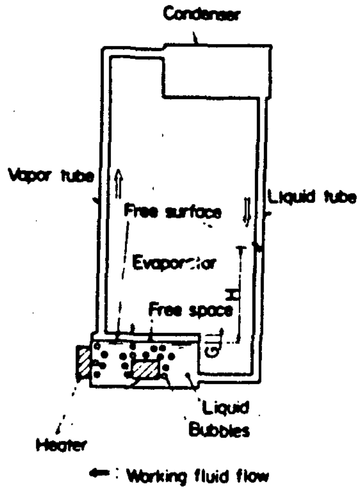


Exotemp's CD2 cooling system shirt (left) has tubing sewn in the fabric at 1-in. intervals to carry water cooled by ice. Canadian Sea King pilots are wearing the shirts under chemical warfare suits. In addition, the Canadian Directorate of Aerospace Support Engineering has sent a new chemical warfare mask and hood system (right) to crewmembers of Sea King helicopters, C-130s and Challengers in the Persian Gulf region.

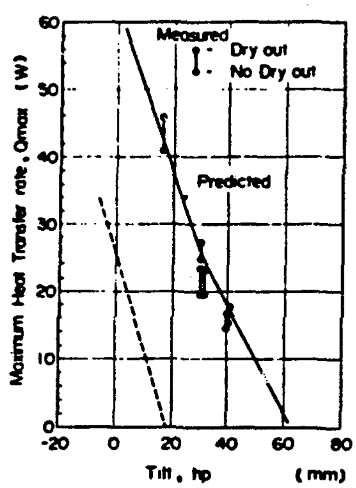
D-10. Picture of Ice-based Microclimate Cooling System



D-11. Schematic of a Phase-change Heat-storage Module

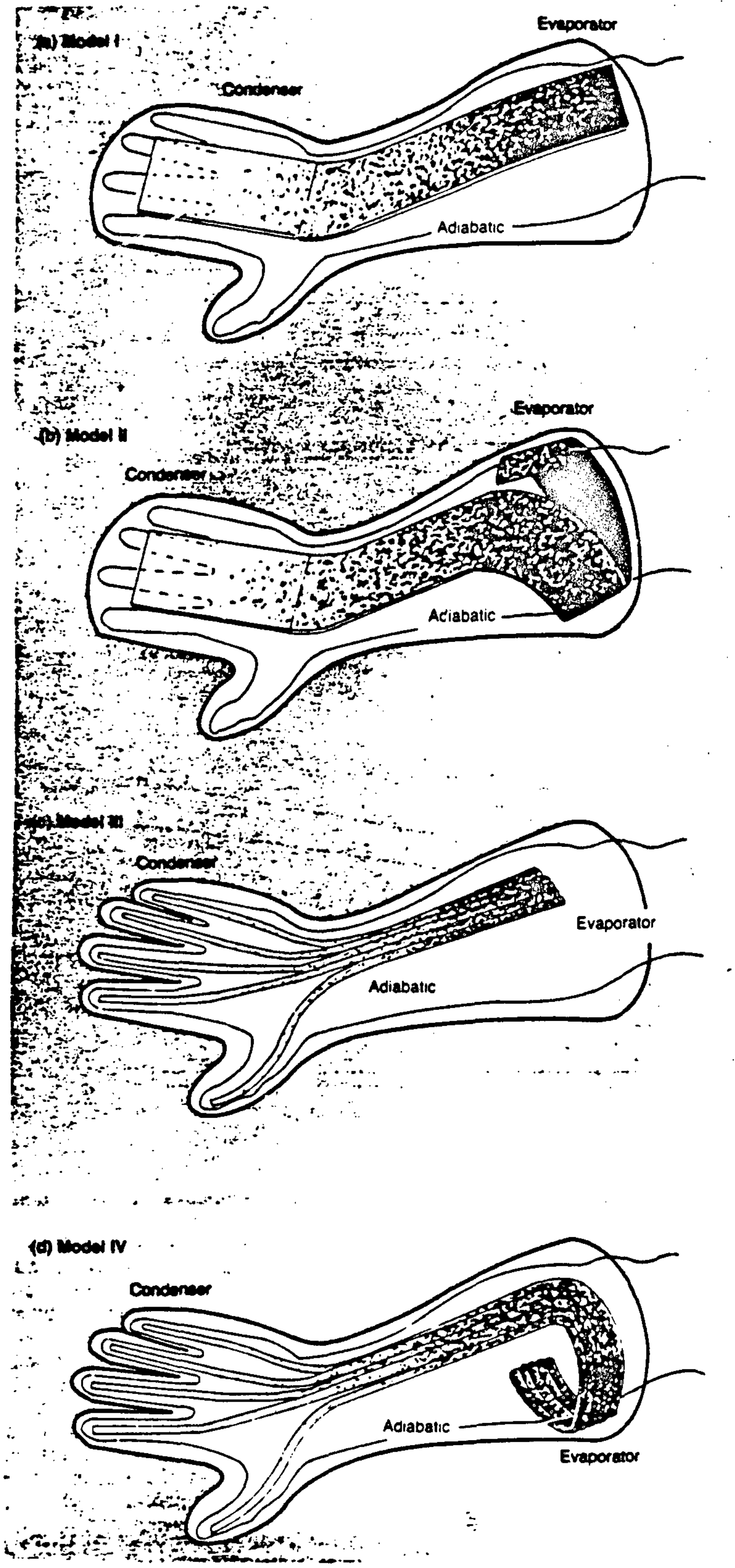


Two-phase closed loop thermosyphon



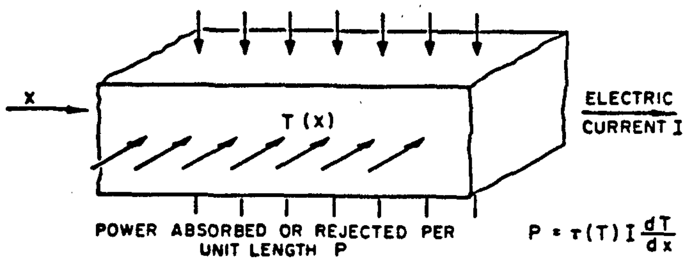
Comparison between the measured and predicted maximum heat transfer rate

D-12. Schematic of Gravity Assisted Thermosyphon

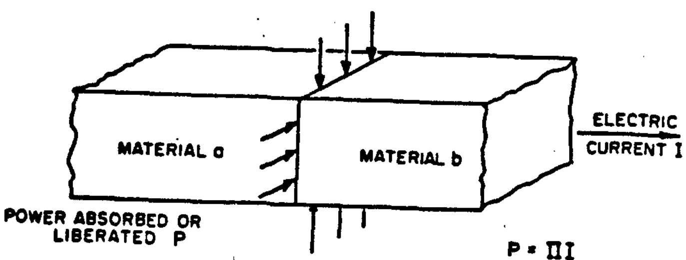


Models of cold weather handwear with heat pipes: (a) mitten with flat flexible heat pipe with condenser at posterior of elbow; (b) mitten with flexible tubular heat pipe with condenser at anterior of elbow; (c) glove with flat flexible heat pipe with condenser at posterior of elbow; (d) glove with flexible tubular heat pipe with condenser at anterior of elbow

D-13. Schematic of Heat Pipes Employed in Cold Weather Gloves

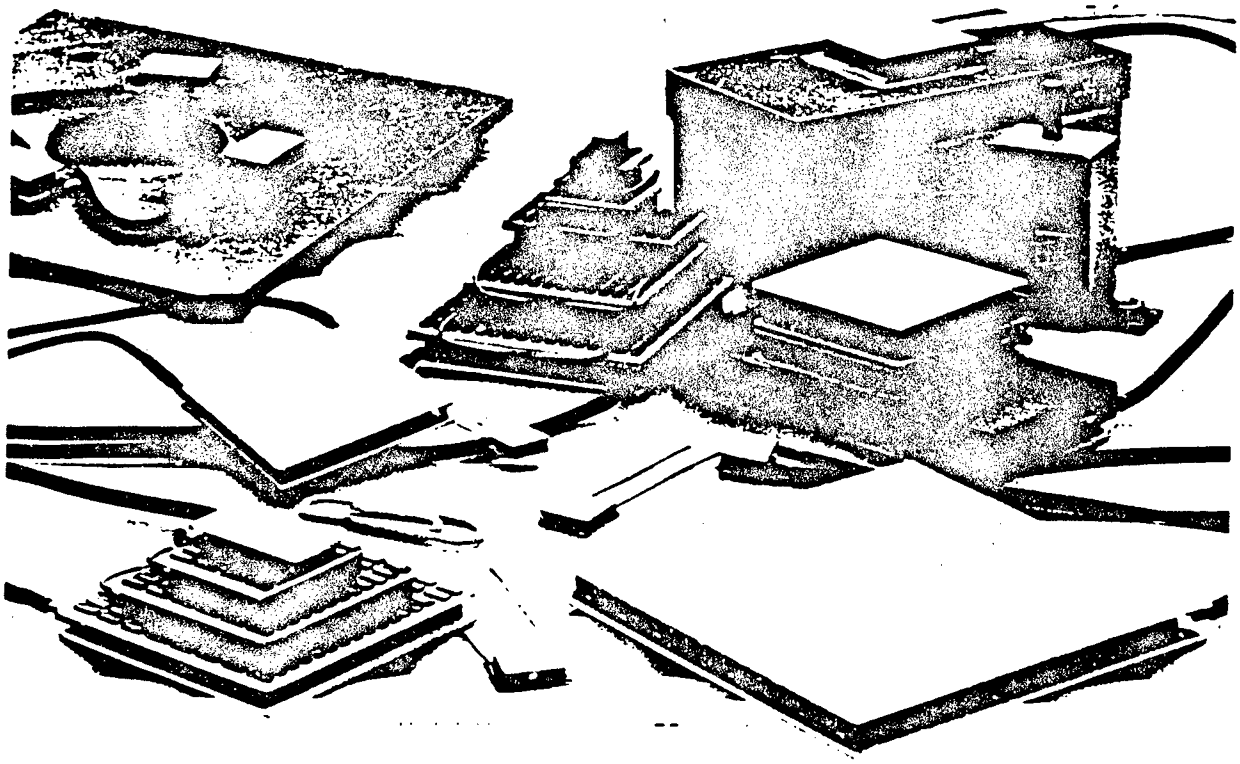


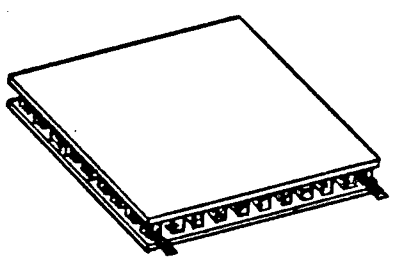
Thomson effect



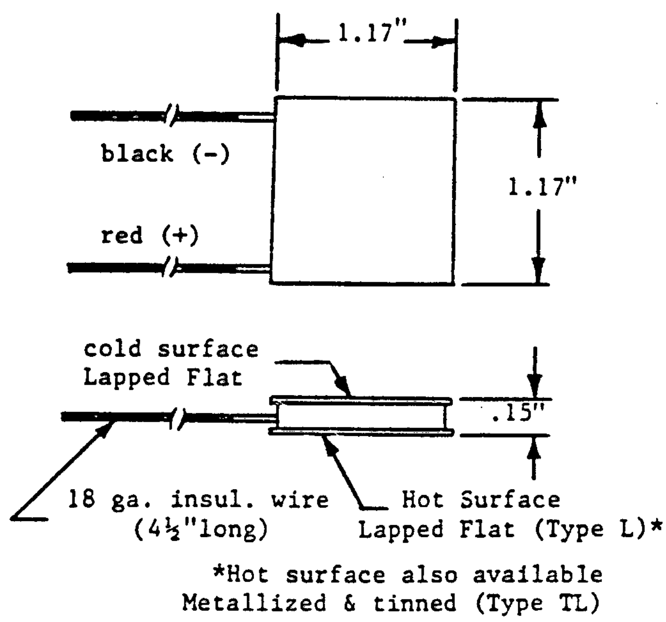
Peltier effect

D-14. Schematics of the Thomson and Peltier Effects





Available in 3, 7, 11, 17, and 35 thermocouple sizes in addition to full 71 couple size. Refer to Module Specification Tables for performance and dimensional data.

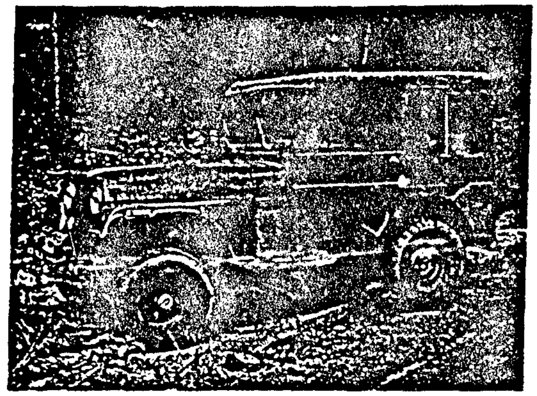


D-15. Thermoelectric Chips

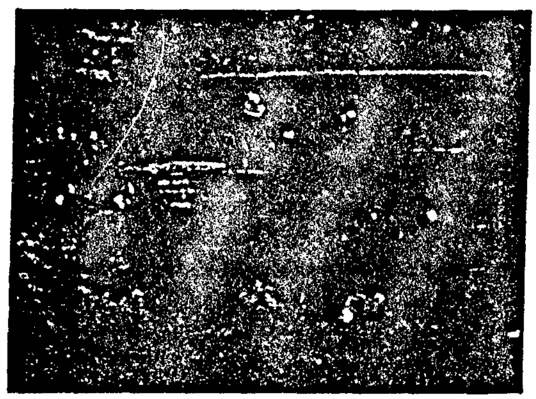
Comparative Imagery

Photographs of typical imagery utilizing night vision devices.

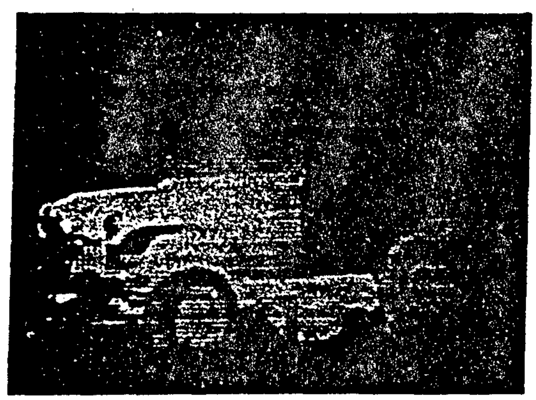
(1) Natural (unaided) daylight photograph



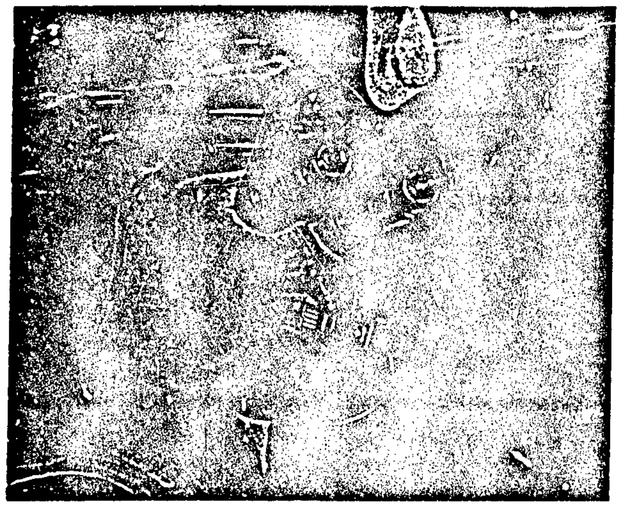
(2) Through an image intensification device



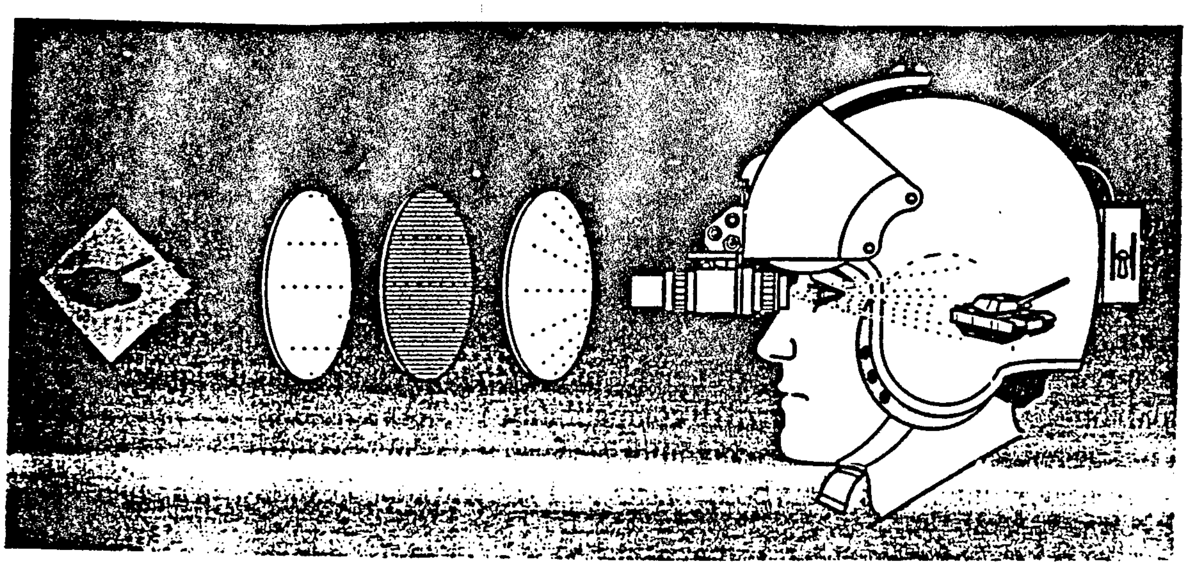
(3) Through infrared device



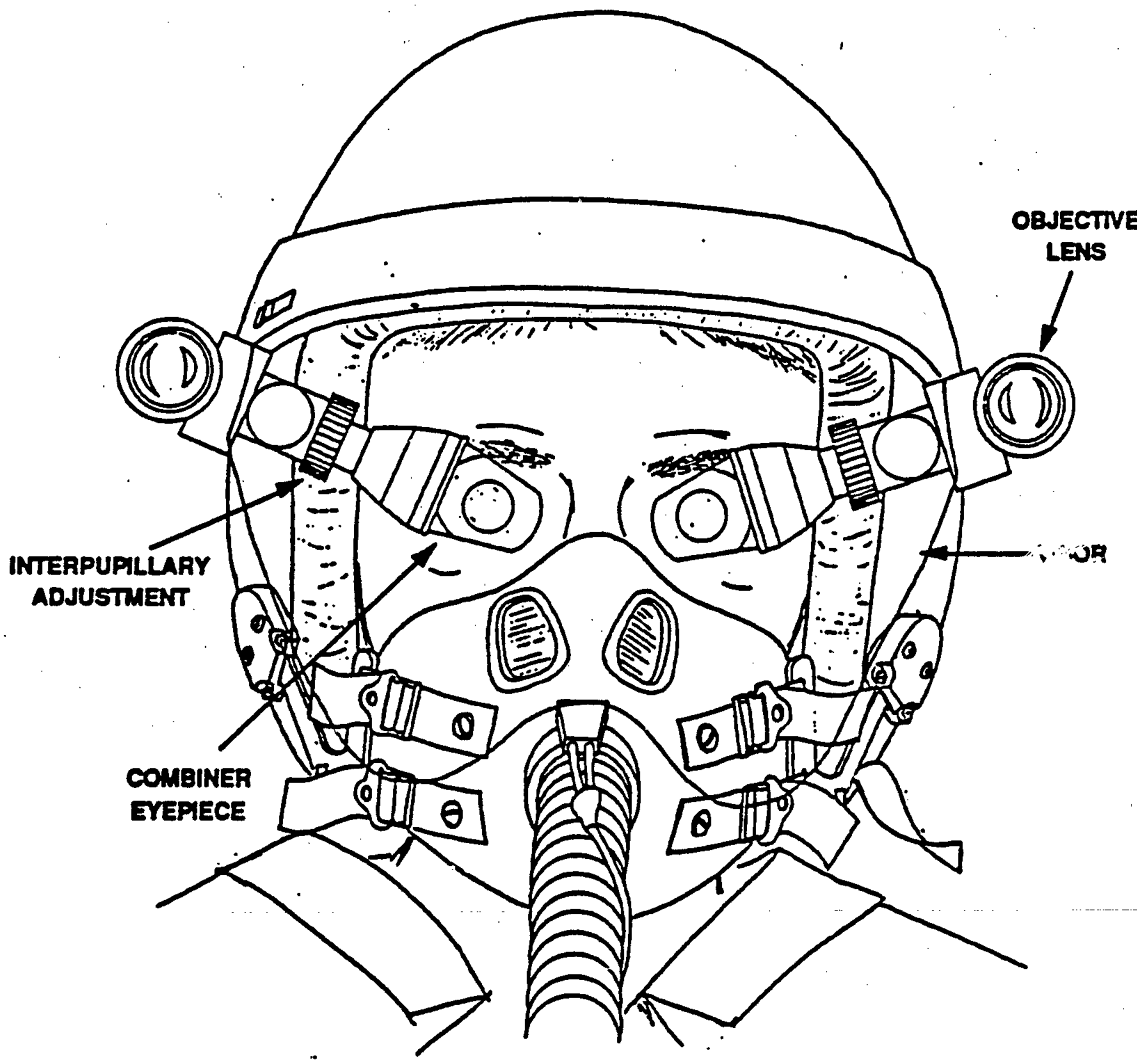
D-16. Picture Comparison of Infrared and Image Intensification



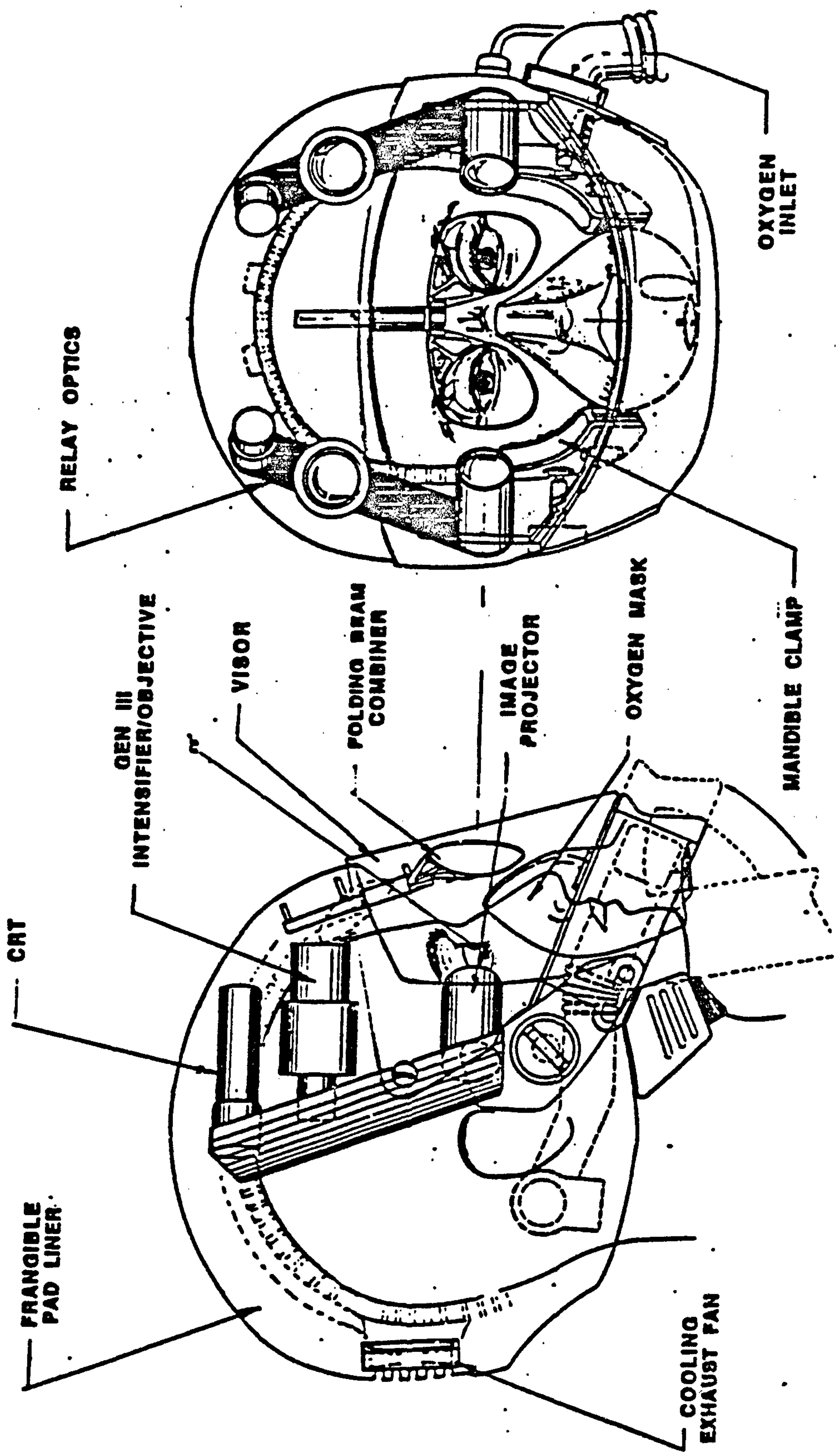
Aviator's Night Vision Imaging System (ANVIS)



D-17. Schematic of Pilot's Night Vision System



D-18A. Schematic of Pilot/Infantryman's Night Vision System (1 of 2)

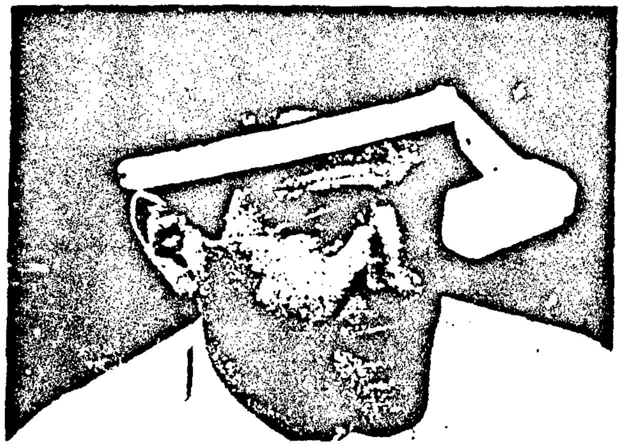


D-18A. Schematic of Pilot/Infantryman's Night Vision System (1 of 2)

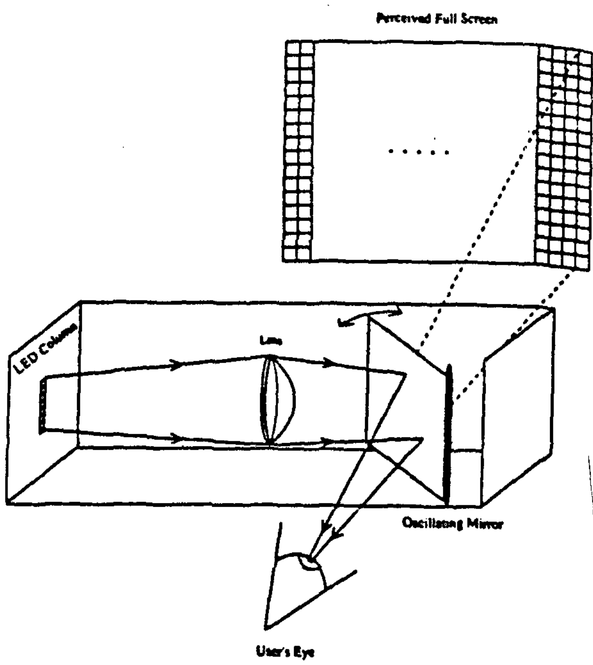
Sextant's Airbus A340 HUD stows when not in use. The glass combiner folds and the whole assembly electrically retracts into the overhead.

Binocular helmet-mounted display for helicopter pilots shows flight information, weapons symbology and infrared or night vision imagery.

D-19. Photos of Heads-up-display Technology

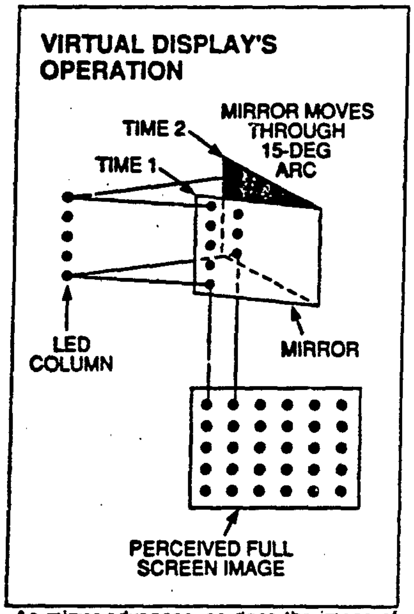


The display is positioned in front of one eye using an adjustable headband. The other eye continues to view the environment.

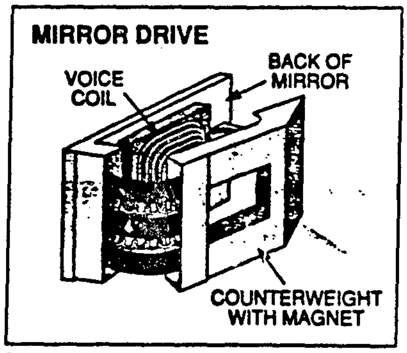


Schematic of the display's design. A linear array of LEDs is driven with one column of imaged data at a time. The horizontally oscillating mirror (50 Hz) scans the column across the observer's retina. The focusing lens serves to create a virtual image of the display about 2 ft in front of the observer and to correct for the user's spherical refractive error.

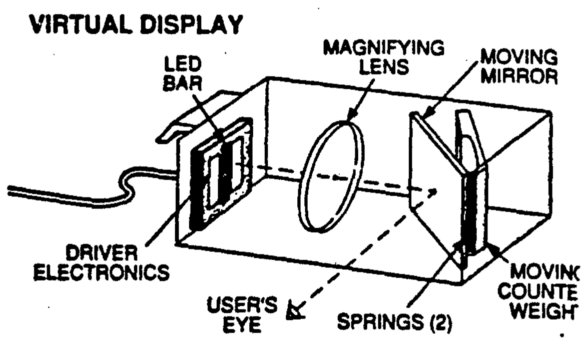
D-20. Schematic of Scanning Mirror/Vibrating Mirror



As mirror advances, so does the image of the column of LEDs. Because of an optical interrupt at maximum deflection, the system is self-correcting and does not need to know the mirror's resonating frequency.

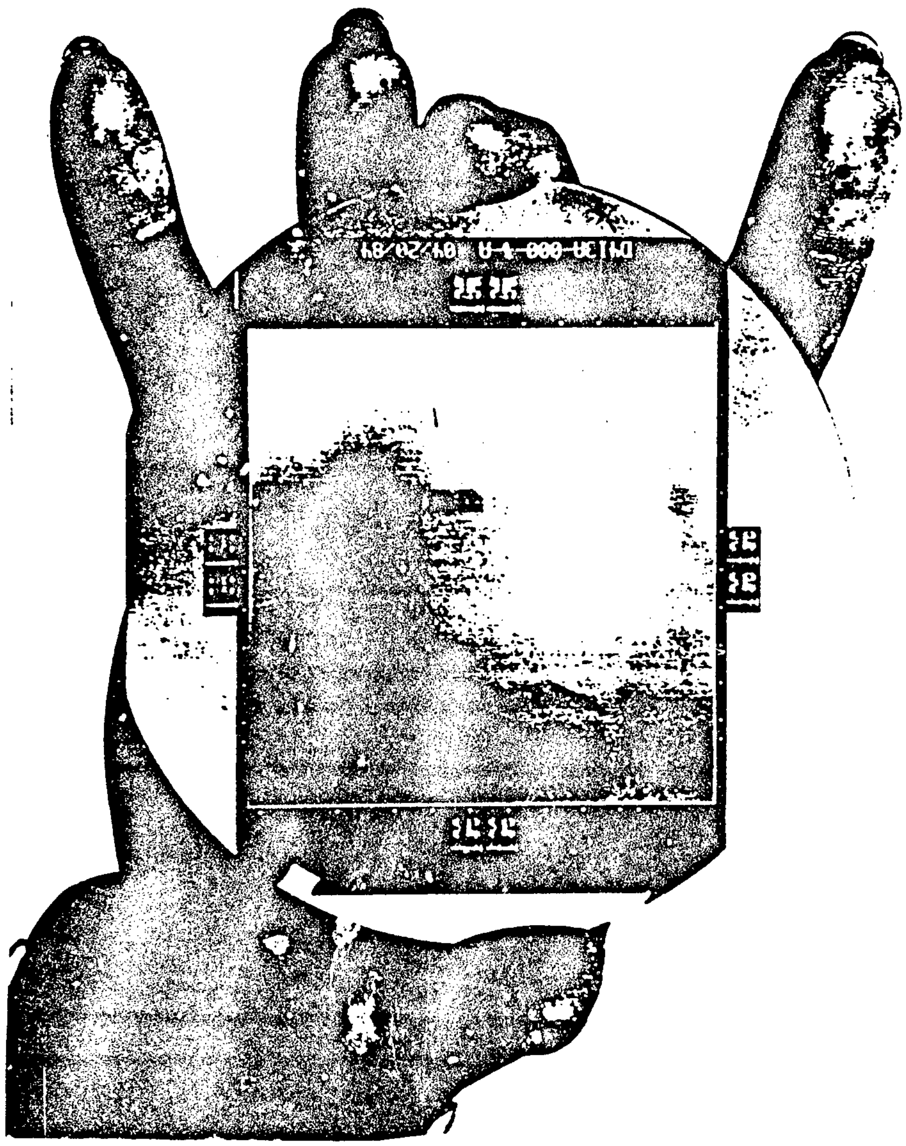


During operation, a voice coil attached to the mirror's back acts against a magnetic counterweight, setting the entire assembly in motion. Because the resonant frequency of the counterweight cancels that of the mirror, the display remains vibration-free.



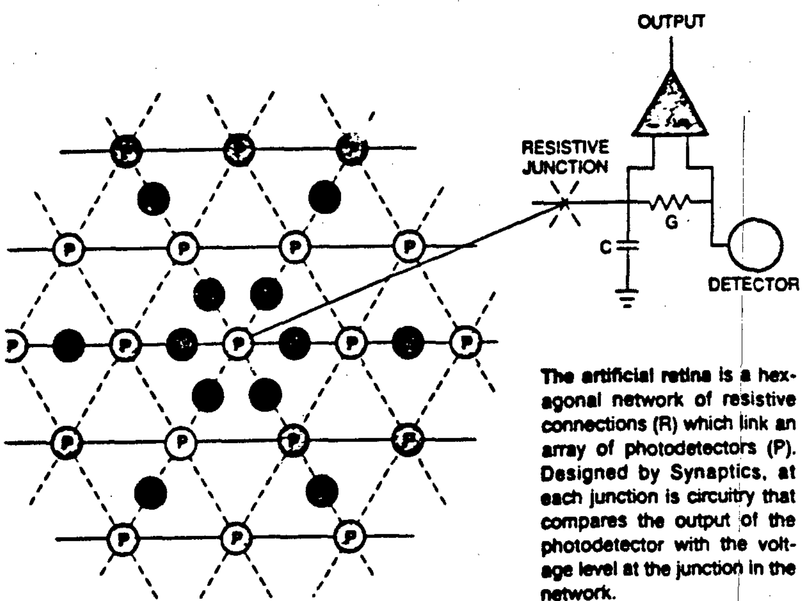
Private Eye virtual display measures 1.2 × 1.2 × 3.5 inches, weighs 2.5 oz, and operates on 5V dc. Its perceived image is 50 times screen size.

D-21. Schematic of Scanning Mirror/Vibrating Mirror



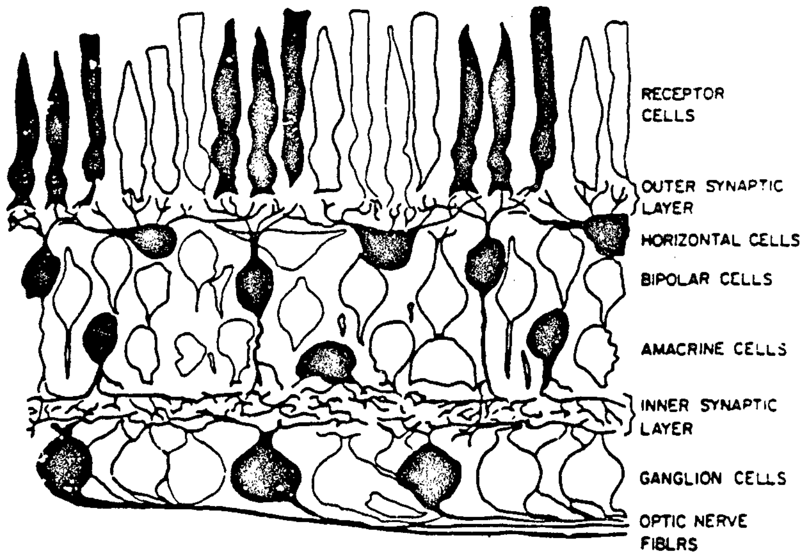
This CCD Imager designed by Tektronix has 4.2 million light sensing picture elements arrayed on 2.8 inches of silicon.

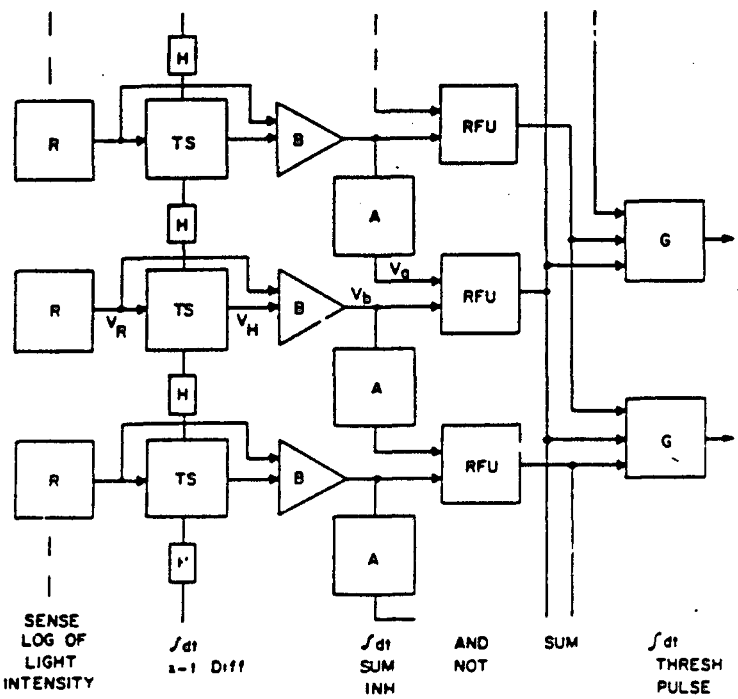
D-22. Photo of an Intelligent Photosensor (CCD Imager)



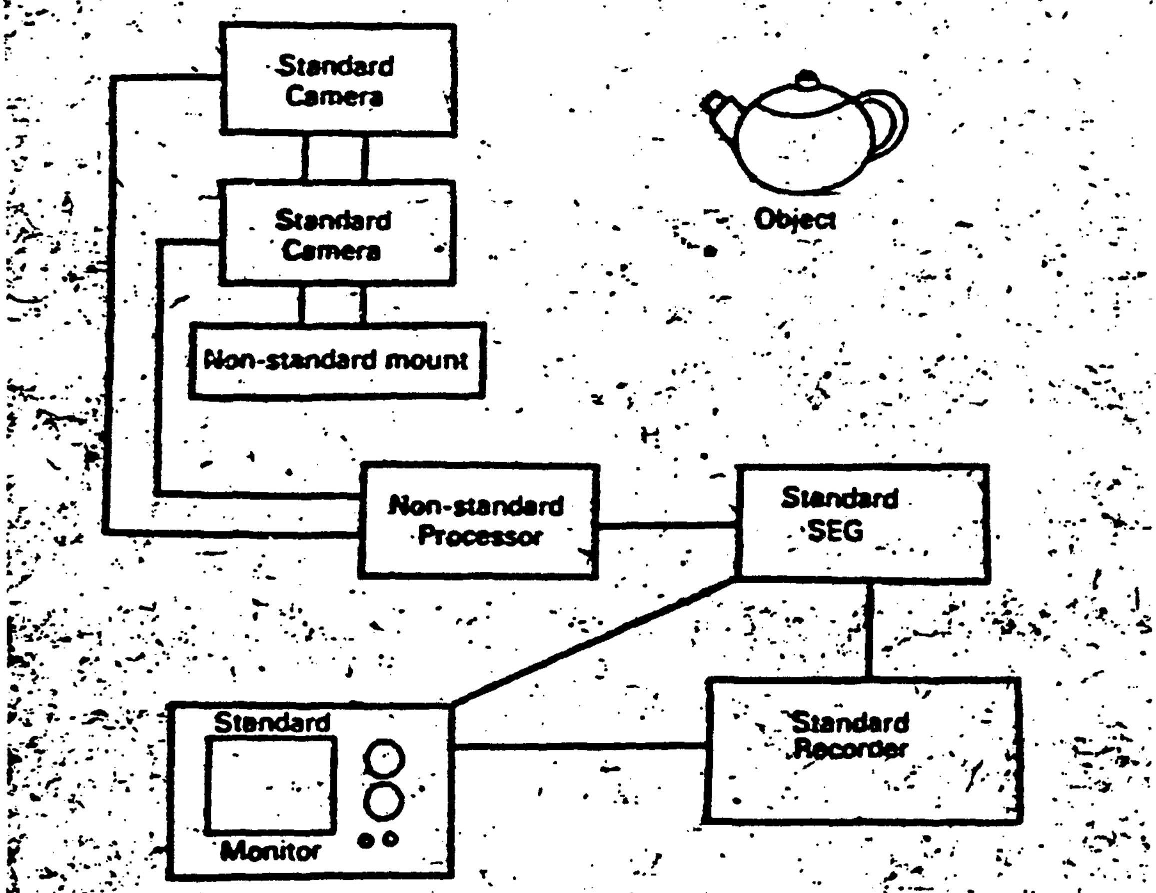
The artificial retina is a hexagonal network of resistive connections (R) which link an array of photodetectors (P). Designed by Synaptics, at each junction is circuitry that compares the output of the photodetector with the voltage level at the junction in the network.

D-23. Schematic of Photo Detectors Arranged as an Artificial Retina





D-24. Schematic of Human Thought Processes vs. Computer Thought



Typical system showing standard and non-standard parts.

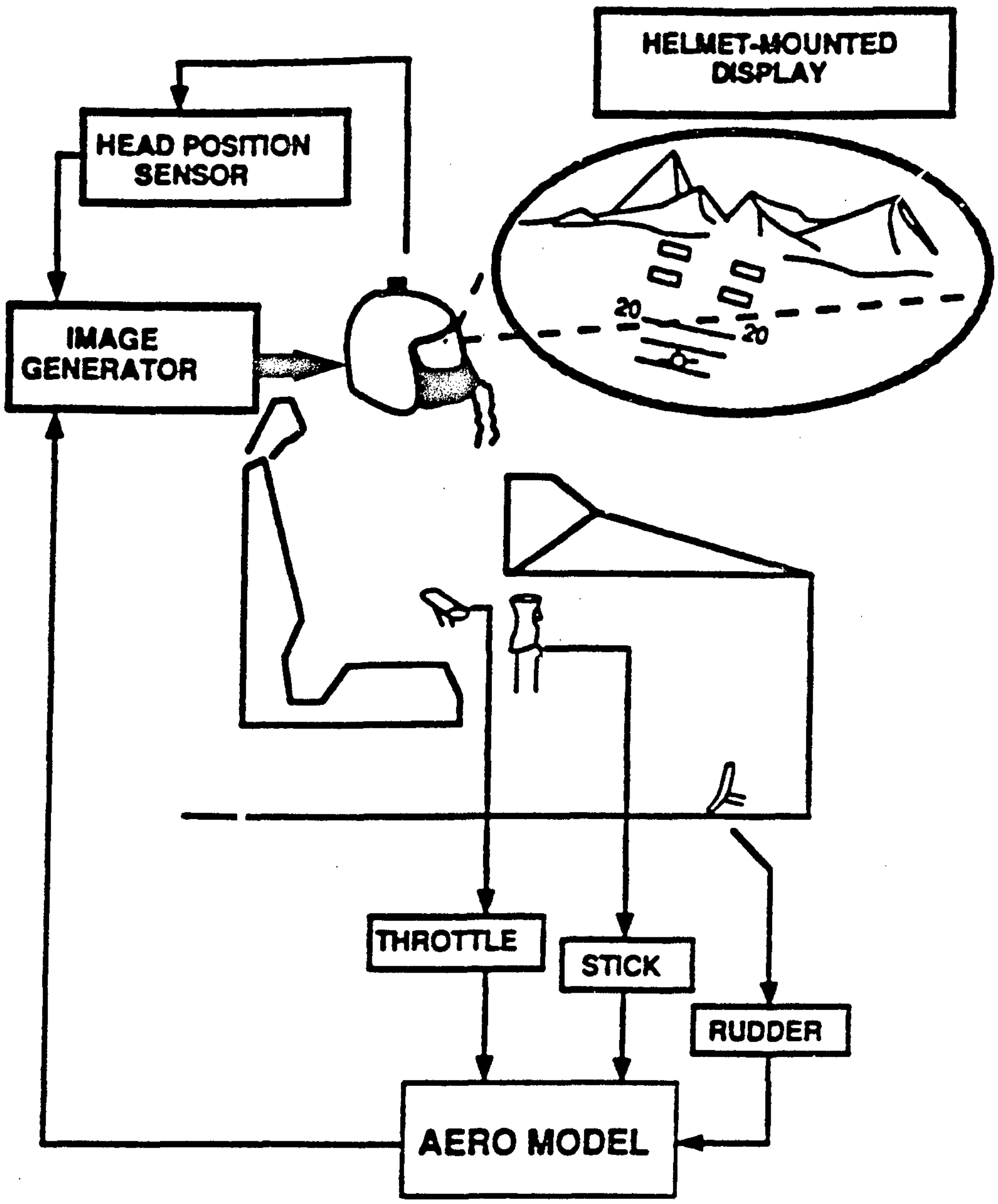
D-25. Schematic of Visidep Vertical Disparity

Virtual reality *allows users to step into a computer-generated world. Experts believe this will fundamentally change the way engineers do their work.*

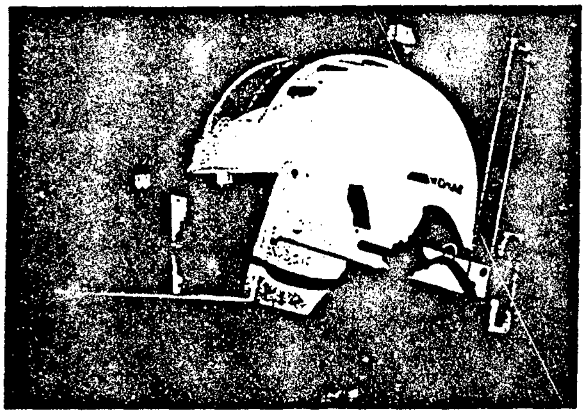
D-26. Photo of a Virtual Reality System (1 of 2)

Through the looking glass. By combining 3-D headgear and gloves with its own software, Autodesk is developing an interface that will one day allow users to physically interact with AutoCAD models.

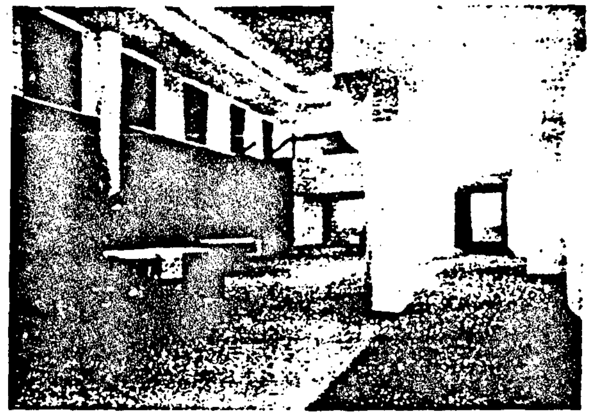
D-27. Photo of a Virtual Reality System (2 of 2)



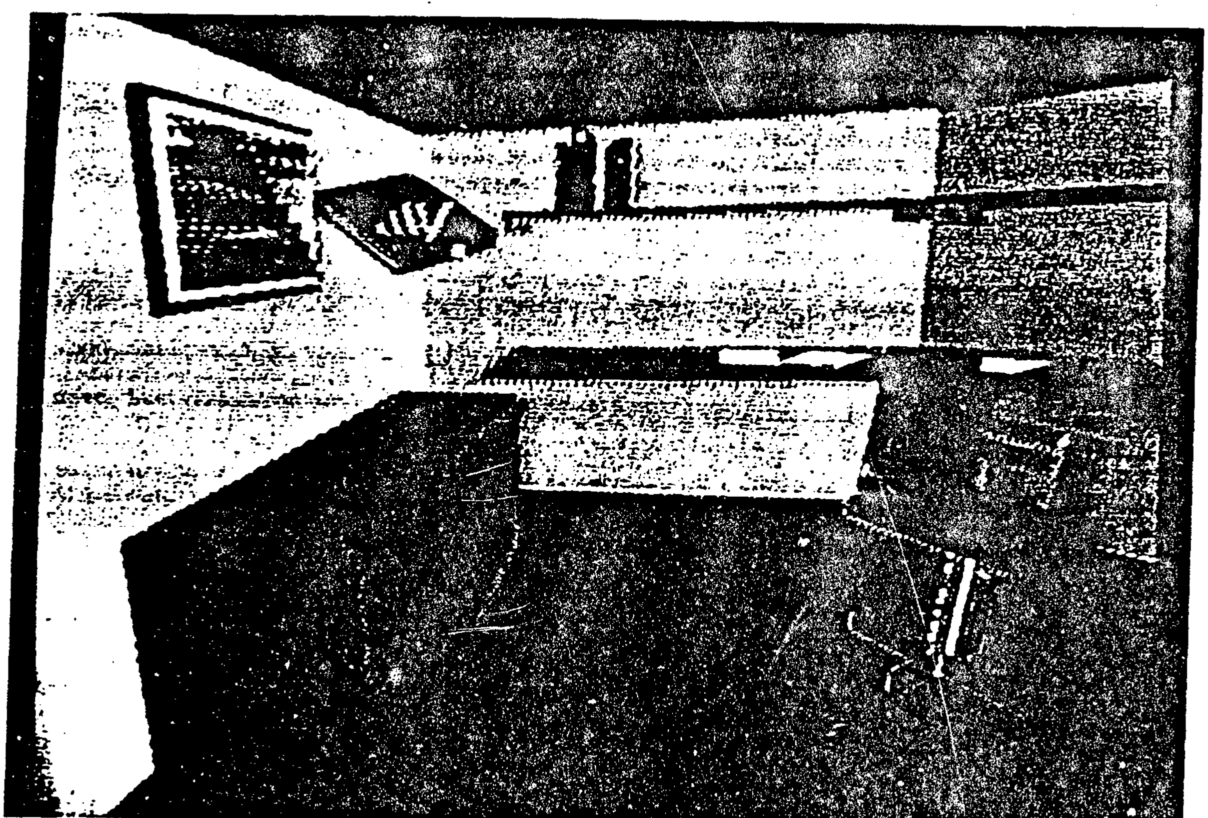
D-28. Schematic of a Virtual Reality Flight Simulator



Visual vanguard. Widely regarded as being in the vanguard of virtual technology, University of North Carolina at Chapel Hill researchers have designed numerous head-mounted displays This model was built in collaboration with the U.S. Air Force Institute of Technology

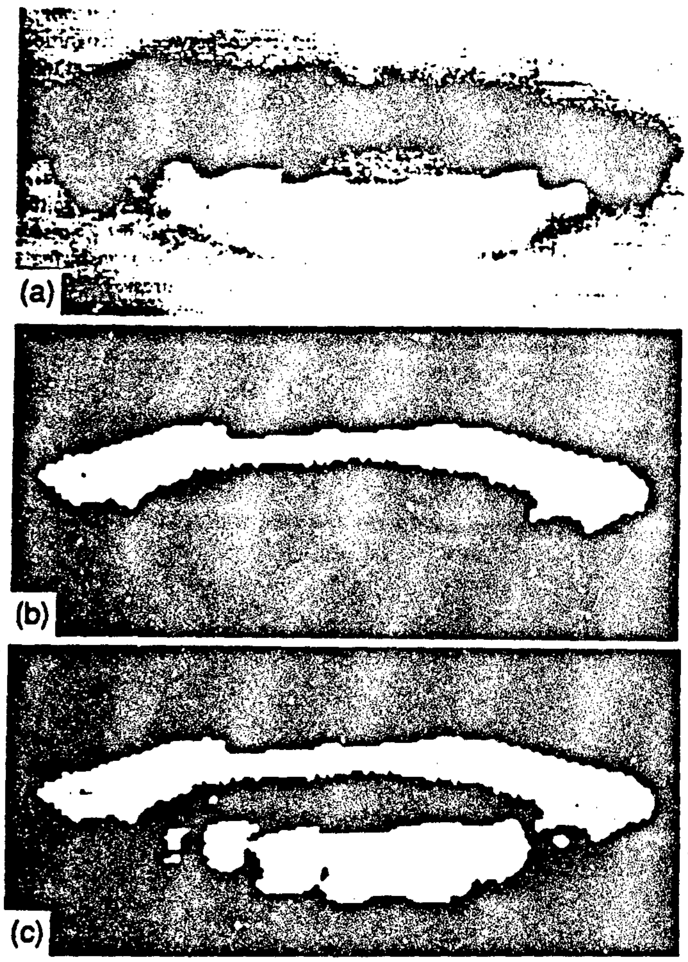


Guided tour. Walkthrough, developed at the University of North Carolina at Chapel Hill, enables users to take a guided tour through a representation of a building that has been modeled using AutoCAD.

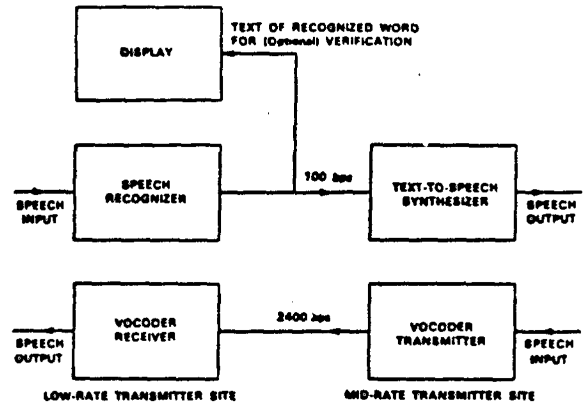


Cyberspace playhouse Researchers ultimately hope to build systems running on portable or desktop systems that can render detailed images with smooth movement. Shown is a closer view of an Autodesk virtual-reality display

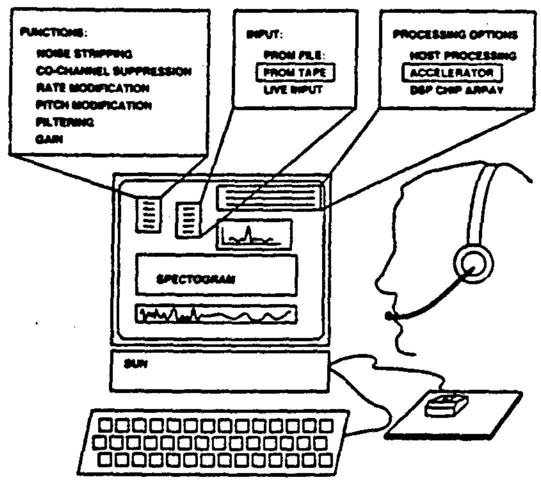
D-29. Photo of a Virtual Reality Simulation



Example of mouth shape images (/a/): (a) original image; (b) binary image (excluding teeth); (c) binary image (including teeth).

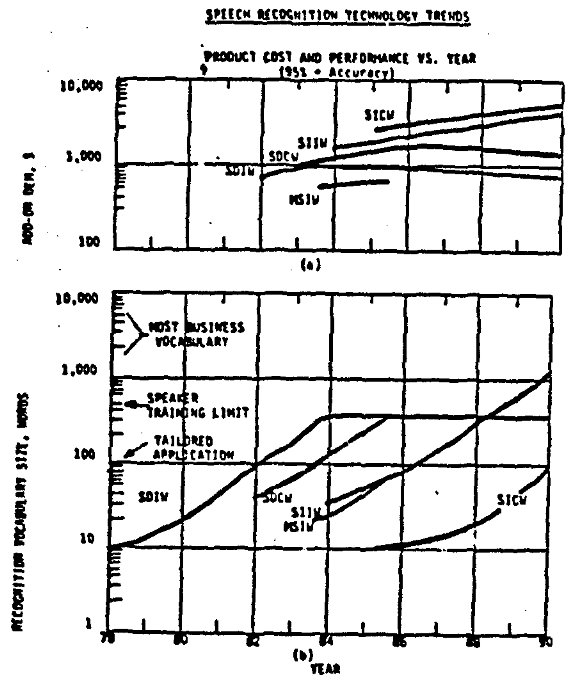


System concept for recognition-based speech communication with asymmetric link capacities.



System structure and user interface for interactive speech enhancement workstation.

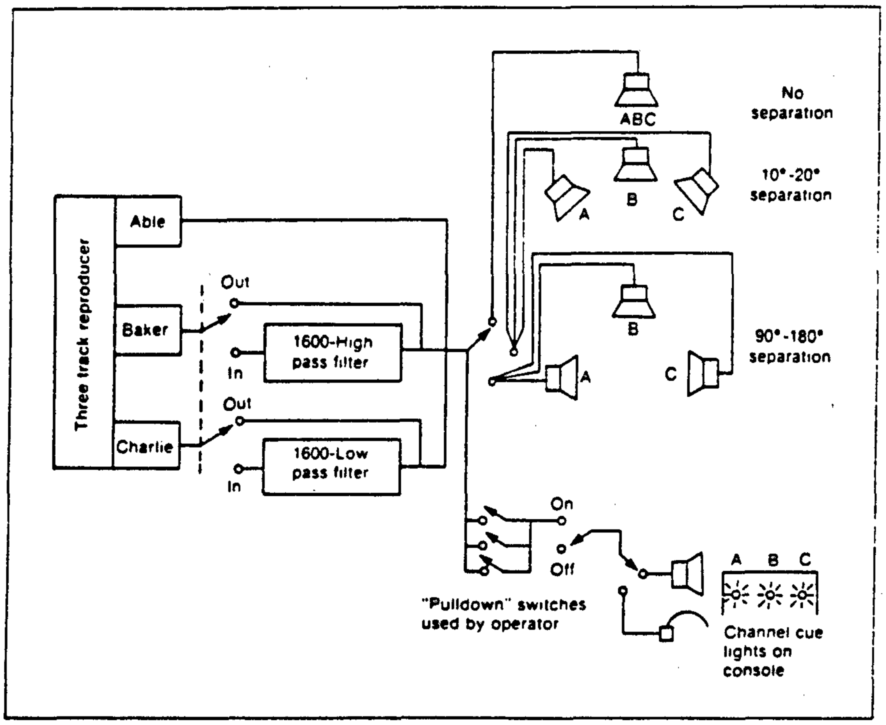
D-30. Photo of the Coupling of Voice Recognition With Video



Speech Recognition Technology Trends

SDIW: speaker dependent isolated word
SIIW : speaker independent isolated word
SDCW: speaker dependent connected word
SICW: speaker independent connected word
MICW: multiple speaker isolated word

D-31. Graph of Speech Recognition Technology Trends



Schematic representation of the listening arrangements studied by Spieth, Curtis, and Webster (1954). On each trial the listener was presented with two simultaneous messages, each spoken by a different recorded voice. The two voices were always the same sex. Voices were not consistently paired with input channels. An example of a message pair might be:

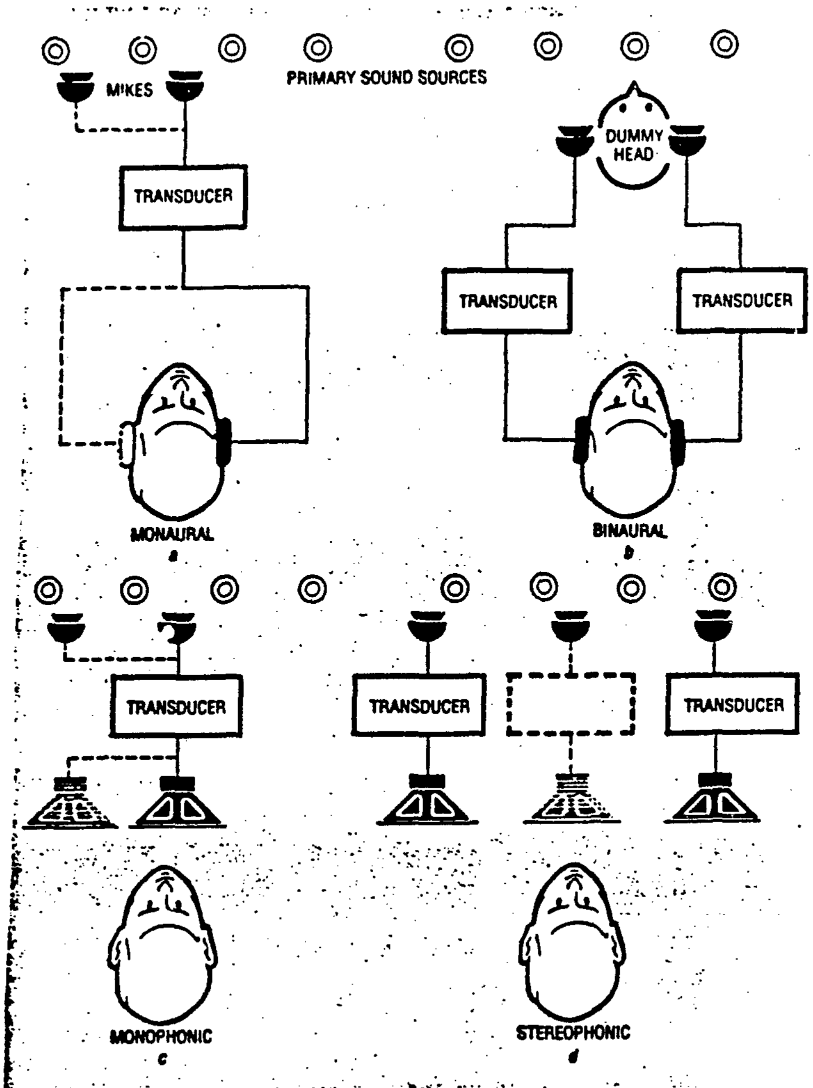
Channel A: Oboe, this is Able 2. Where in box 5 is the triangle? Over.

Channel B: King, this is Baker 1. What box contains two circles? Over.

Each message contained a code name (e.g., Oboe) that was assigned to the listener, the name of the channel calling (e.g., Able), the talker number (e.g., 2), and a question concerning a five-box visual display in front of the listener. The listener's task was to report the channel and talker calling and answer the question posed. The listening arrangement permitted investigation of the effects of four variables on selective listening performance:

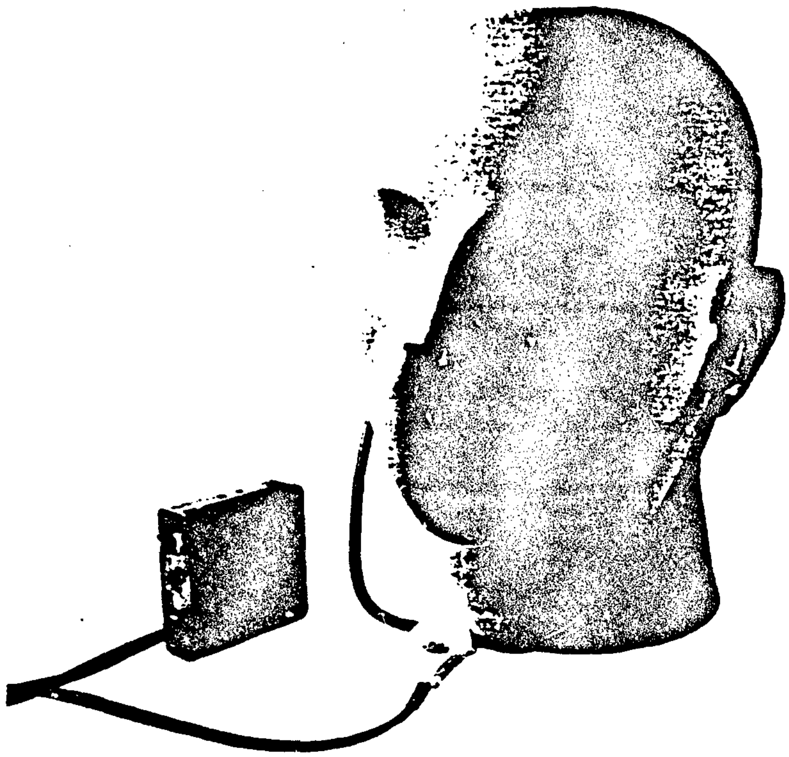
1. Speaker separation: (a) All three channels used could be branched into a single speaker 3 feet in front of the listener; (b) each channel could be branched to its own speaker, with adjacent speakers separated horizontally by 10 degrees (left, right, center); or (c) each channel could be branched to its own speaker, with adjacent speakers separated by 90°.
2. Audio spectrum shaping: A 1600-Hz low-pass filter could be inserted into the "Charlie" channel and a 1600-Hz high-pass filter could be inserted into the "Baker" channel.
3. Visual channel indication: Indicator lights specifying the relevant channel could be set in an "on" or an "off" mode.
4. Pulldown feature: Under some conditions the listener could "pull down" or switch the chosen message from the originating speaker into a nearer (1 foot distant) speaker or into headphones.

D-32. Schematic of the Listening Arrangement Possibilities for Binuaral



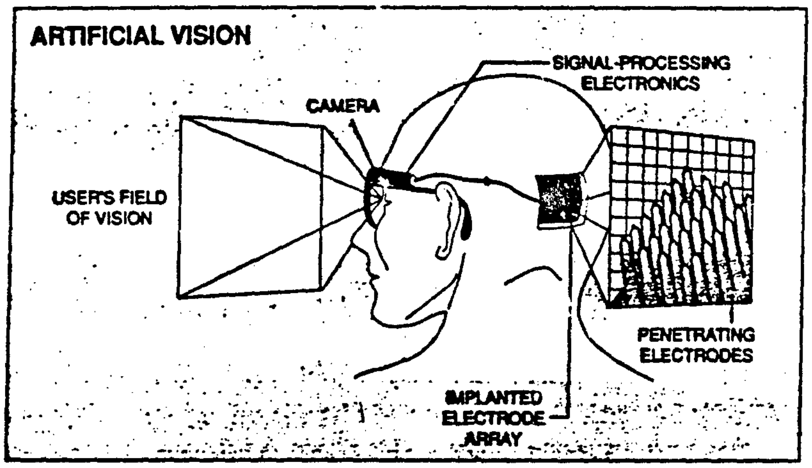
SOUND REPRODUCTION SYSTEMS; monaural (*a*), binaural (*b*), monophonic (*c*), and stereophonic (*d*).

D-33. Schematic of Sound Reproduction Systems



-IN TRUE BINAURAL RECORDING, a mechanical replica of the human head and ears ensures the proper capture of phase relationships. This is the *MKE 2002* binaural dummy-head stereo-microphone setup from Sennheiser. To hear the special stereo effects, the recording must be listened to with high-quality headphones.

D-34. Picture of Recording Head Replica



Artificial vision, if successful, could work as follows: A head-mounted charge coupled device encodes the visual scene in front of a blind individual. Camera output passes, via signal processing electronics, to an implanted electrode array. Selected electrodes stimulate neurons of the visual cortex to replicate the scene.

D-35. Schematic of Artificial Vision

D-36. Schematic of Body Armour-Powered

APPENDIX E

TECHNOLOGIES TO MONITOR

SUMMARY OF TECHNOLOGIES THAT NEED TO BE MONITORED

Technology	Current/Recent R&D Efforts	Active Organization(s)
Oxygen Storage (3.1.1)	Cryongenic oxygen storage for individual respiratory protection in space.	NASA, Portable Life Systems, Lyndon B. Johnson Space Center
Oxygen Rebreathing (3.1.3)	Closed system diving tanks.	U.S. Navy Experimental Diving Unit
Oxygen Generation from Plant/Algae Growth (3.1.4.4)	Algae photobioreactor for oxygen production in a CELSS.	University of Michigan, Ann Arbor
	Tubular photobioreactor for continuous oxygen production and carbon dioxide removal.	Tonen Corporation (Saitama, Japan)
	Growing algae in an inert atmosphere to produce oxygen and hydrogen from water.	Oak Ridge National Labs
	CELSS using biological systems to recycle air, water, and waste products.	NASA Ames Research Center
Image Intensifier Tubes (3.3.1)	AN/AVS-6 Night Vision Equipment.	ITT Defense (developers of tube)
	Eagle Eye™ low profile night vision goggle system.	Night Vision Corporation
Scanning Mirrors (3.3.3)	Private Eye™ display.	Reflection Technology
Intelligent Photosensors (3.3.4)	Model of human retina.	Synaptics Incorporated, San Jose, CA
	Integration of neural networks.	California Institute of Technology

Technology	Current/Recent R&D Efforts	Active Organization(s)
3-D Imaging (3.3.6)	VISIDEP™ advanced alternating frame technology.	South Carolina University
Geometric Reasoning (3.3.7)	Very High Speed Integrated Circuit (VHSIC) mission processor.	Westinghouse
	Aided Target Detection/Classification System.	Westinghouse and Marietta
Voice Recognition (3.4.1)	Simulated speech recognition systems.	Wright Patterson AFB
	French based systems.	French Ministry of Defense
	Advanced Fighter Technology Integration (AFTI)	U.S. Army Avionics R&D Activity
	Voice recognition with video.	Osaka University Medical School, Japan
Wireless LAN's (3.4.2)	Miscellaneous applications.	See computer network journals
Laser Communications (3.4.4)	Sub-based laser communications.	U.S. Navy (branch not specified)
	Land based point-to-point.	U.S. Army and Navy (branches not specified)
Advanced Data Processing (3.5.1)	Holographic memory chips.	Bell Communications Research
	Highspeed data acquisition.	AT&T Microelectronics
	X-ray lithography.	Hitachi
Optoelectronics (3.5.3)	Fiber Optic Control System Integration (FOCSI).	NASA Lewis Research Center
	Optical neural networks.	Mitsubishi Electric Corporation
	Binary optics.	DARPA

Technology	Current/Recent R&D Efforts	Active Organization(s)
Artificial Sight and Optical Imaging (3.5.5)	Artificial vision.	University of Utah, Department of Bioengineering
Miscellaneous	Night vision and electro-optics devices.	NVEOD
	Soldiers command, control, and communications.	CECOM
	Modular Universal Laser Equipment (MULE).	USMC
	Direct energy protection.	NRDEC
	Individual power.	BRDEC
	Miniaturized electronic components and batteries.	Electronics Technology and Devices Laboratory
	Weapons integration.	ARDEC
	Human factors.	HEL

APPENDIX F

PROGRAM PLANS

TECHNOLOGY AREA: **RESPIRATORY PROTECTION**

PROMISING TECHNOLOGIES:

Oxygen Generation from CO_2 Using Superoxides
Oxygen Generation from CO_2 Using Electrolysis
Oxygen Generation from Water Vapor Electrolysis

ASSUMPTIONS:

(1) Today's mechanical/chemical filters will be replaced with some form of oxygen supply or generation.
(2) A closed-circuit rebreathing apparatus will be employed.
(3) Power will be available for electrolysis and respiratory cooling.

BACKGROUND:

Rebreathing apparatuses that employ oxygen generation from carbon dioxide using superoxides already exist and are in use for underwater exploration. Oxygen generation from CO_2 and water vapor electrolysis are still developmental; prototype systems have been constructed and tested for space station applications.

An AIPS will not be able to rely completely on oxygen generation, thus, some form of oxygen supply will be included in the system. The goal for AIPS' respiratory system will be to minimize use of this supply by generating addition oxygen from sources that, under normal circumstances, would be discarded by the system.

RESEARCH NEEDED FOR DEVELOPMENT:

Improvements are needed to current superoxide rebreather units for AIPS applications. These include: selection of a lightweight, inexpensive, long lasting superoxide; development of a control system that optimizes use of the oxygen source and superoxide, while utilizing all carbon dioxide exhaust; and development of a mechanism for cooling the recirculated breathing air.

Improvements needed to water vapor and CO_2 electrolysis units include: down-sizing current prototype models for individual portability, while maintaining the required level of oxygen production; selecting and electrolytic cell efficient at oxygen production from exhaled air; designing a control system to regulate input and output to the cell reactor; investigation the possibility of adding moisture vapor collected from a protective suit interior; and developing a mechanism of cooling reacted air.

DEVELOPMENT APPROACH:

At a minimum, AIPS should incorporate the superoxide technology. Even if oxygen supply/generation are not needed in the future, it would be feasible to integrate superoxides with current cartridge filters in a rebreather system for extended filter life.

An apparatus for testing a variety superoxides and respiratory control systems needs to be constructed. The apparatus should be capable of simulating the human respiratory system, to include a humidity and carbon dioxide generating device. The test apparatus would require integration of an oxygen supply unit, a breathing machine, parameter sensors, developmental system, and a personal computer for data collection/analysis. State-of-the-art breathing machines should be investigated prior to "reinventing the wheel" by designing test equipment that already exists.

Further engineering analysis into oxygen generation from water vapor and CO_2 electrolysis should be conducted prior to developing any hardware. Contact should be made with NASA and contractors previously involved with these efforts (see points of contact list and technology write-ups). Documentation and test data on prototypes should be acquired and reviewed. A detailed analysis of existing oxygen generation units will be necessary for effectively modifying today's systems for AIPS applications in the future. Personnel knowledgeable in electrochemistry will be needed.

EQUIPMENT NEEDED FOR DEVELOPMENT:

Oxygen supply unit.
Carbon dioxide supply unit.
Moisture generator/CO_2 mixer.
Sensors: temperature, pressure, humidity, carbon dioxide.
Breathing machine.
Thermal control unit.
Power supply.
Personal computer.
Superoxides.
Rebreathing mask.

TECHNOLOGY AREA: **THERMAL MANAGEMENT**

PROMISING TECHNOLOGIES:

Phase Change Materials
Heat Pipes
Thermoelectricity

ASSUMPTIONS:

(1) AIPS will require some form of thermal management such as suit cooling, hood ventilation, respiratory cooling, or equipment cooling (electronics, heat signatures, etc.).
(2) Power will be made available. Note: only thermoelectricity requires power; phase change materials and heat pipes can be employed passively.
(3) Thermal management technologies can be integrated into the system without significantly burdening the soldier.

BACKGROUND:

Phase change materials, heat pipes, and thermoelectricity are by no means novel technologies, however, integrating them with AIPS will require additional research and engineering. Some applications related to AIPS do exist today, however, most are in developmental or prototype stages (PCM clothing, heat pipe glove). These technologies provide alternatives to today's microclimate cooling devices. A brief comparison of thermal management technologies is shown in the following table.

	Function	Concept	Method of Employment	Power Needs
PCM's	Thermal storage	Latent heat of fusion	Active or passive	Recharging
HP's	Thermal Transfer	Latent heat of vaporization	Active or passive	Pump (optional)
TE	Cooling or heating	Peltier/Seeback effects	Passive	DC input
MCC	Cooling	Mechanical	Active	Pump/compressor

RESEARCH NEEDED FOR DEVELOPMENT:

For all the promising thermal management technologies, breakthroughs are needed in developing materials that operate efficiently at near ambient temperatures. This research is currently being conducted by manufacturers of cooling/heating components that employ these technologies. These manufacturers will be helpful in selecting materials suitable for AIPS.

Thermal management technologies should be analyzed from a logistics and operational point of view. Factors that should be included in this analysis are: time of operation, duration of thermal management, power consumed during operation, cooling/heating benefit, time between recharge (if necessary), expected operating life of materials, safety issues, ease of replacement/repair, and human factors. An effective comparative analysis will require development of a specific application, operating conditions, and a similar method of technology integration. All three thermal management technologies appear worthy of further investigation.

DEVELOPMENT APPROACH:

Because these technologies are already well-developed, the only need for AIPS is establishing a method of integration. Since the focus of this evaluation was on respiratory protection, rather than body protection, thermal management of the mask/hood assembly is recommended. Possibilities include, but are not limited to, cooling of respiratory air (if a closed-circuit rebreather is used), localized mask cooling, and removal of heat from a hood.

Design requirements will need to be established prior to obtaining any cooling hardware. Thus, a thermal analysis of the item(s) selected will need to be done, in order to acquire cooling requirements, mounting locations, and physical constraints. Once these requirements, in addition to system concepts, have been established, contact should be made with material manufacturers to select materials appropriate for the application. If early engineering analyses indicate that all three technologies are capable of meeting design requirements for a particular application, then all three should be acquired and tested in a prototype respiratory system.

EQUIPMENT NEEDED FOR DEVELOPMENT:

Prototype mask.
Thermocouples.
DC power source for thermoelectric chips.
Test subject or mannequin head capable of simulating heat generation of a human head.
Closed circuit rebreathing approaches (as needed).
Cooling device for recharging.

TECHNOLOGY AREA: VISION/OPTICS

PROMISING TECHNOLOGIES:

Heads-up Displays

ASSUMPTIONS:

(1) An AIPS helmet will include a heads-up display for presenting critical information needed by the solider.
(2) A narrow display band, mounted to the soldiers helmet visor, will be used under normal operations. If enhanced vision or eye protection is needed, a pull-down screen will be placed in front of the soldier's eyes.
(3) Processing speed will be adequate to present information and display messages as well as graphical images in real time.

BACKGROUND:

Heads up displays already exist in airplane cockpits and armored vehicle control centers. This technology needs to be adapted to the size of a helmet visor, similar to the way SIPE integrates a thermal image display with the soldier's weapon system. During normal operations, the wearer's view must not be hampered or obscured though due the use of heads up displays. When operating in enhanced mode, the display must provide a detailed representation of the soldier's surroundings. Concerns here not only include obstructing the soldier's field of view but overloading him with unnecessary information. Human factors engineering will play a major role in integrating these displays with the soldier.

RESEARCH NEEDED FOR DEVELOPMENT:

Developing a vision system for AIPS will require research into the following areas: video display, image processing, and methods of integrating this technologies with a soldier's helmet and/or protective mask. Display and processing technologies will mature from research conducted by electronics and computer industries; ERDEC only needs to monitor these developments. The major need for ERDEC is to investigate ways to implement the technologies as applications are introduced to the consumer market.

DEVELOPMENT APPROACH:

Adapting current display systems used in fighter planes to a helmet is the main shortfall right now, but one that will be easy to overcome with advancements in video display technology. Current CRT displays are too bulky for helmet integration. Further development of flat screen LCDs for lap-top PCs and miniature TVs offer potential for helmet mounted display systems.

Research being conducted by DARPA and USAF (Wright Patterson AFB) into LCD HUDs needs to monitored.

An analysis of methods for integrating visual displays needs to be conducted by establishing basic design requirements, then identifying state-of-the-art equipment capable of meeting those requirements. This analysis should include the following human factors issues: field of view, focus distance between the soldier's eyes and the display, weight of the helmet mounted equipment (center of gravity), ease of operation (especially with pull-down devices), content of information being presented to the soldier, and duration of use (extended viewing of graphic displays could cause discomfort to the soldier).

Upon completion of the analysis, a prototype vision system should be constructed and tested for compatibility. The system should also be evaluated for manufacturability. Constructing a prototype from equipment whose technology is not yet fully mature enables ERDEC to get involved with the development of the technology, to ensure that it will meet AIPS requirements.

EQUIPMENT NEEDED FOR DEVELOPMENT:

Display hardware.
Helmet and protective mask.
Personal computer or other image processor.

TECHNOLOGY AREA: COMMUNICATIONS

PROMISING TECHNOLOGIES:

Binaural Processing

ASSUMPTIONS:

(1) AIPS will require enhanced hearing and/or auditory protection as part of the soldier's communication system.
(2) Communications and hearing should not be impaired when wearing individual protection (mask/hood).
(3) Current voicemitters will be replaced with electronic microphones.
(4) Computing power and neural network technology will be adequate for implementing a binaural hearing system.

BACKGROUND:

Current mask/hood configurations degrade a soldier's ability to communicate; both speech and hearing are impaired. Incorporating a speaker/microphone assembly into AIPS will enable soldier's to communicate more effectively. Binaural processing can be integrated with a speaker system to enhance a soldier's hearing capabilities and to improve communications between soldier's wearing protective masks and hoods.

Binaural recordings are already on the market. Binaural processing is currently being worked on, the concepts of how the auditory system actually processes signals is in the research phase.

RESEARCH NEEDED FOR DEVELOPMENT:

Basic communication technologies will mature from government and industrial research. ERDEC should monitor developments in technologies that offer alternatives to radio frequency communications, such as laser, millimeter wave, or infrared. ERDEC needs to be prepared to integrate hardware associated with these technologies as it is developed.

For binaural processing, the focus of the research needs to be on how the human auditory system actually processes the binaural signals it receives. The spatial qualities of sound and how the brain interprets the time delay between them needs to be replaced possibly with a neural network. Research also needs to concentrate on how a persons ear shape, facial features, and head size affect binaural processing. Custom fitting of helmets will be too costly for an AIPS, therefore a general system for processing needs to be developed.

DEVELOPMENT APPROACH:

Future research on binaural processing will be conducted by the medical community for the hearing impaired and developers of acoustical equipment for stereo systems. ERDEC needs to monitor this research and hardware that evolves from the development of this technology. ERDEC should also monitor the research of NASA and USAF on the 3-D auditory display.

While novel methods of communications are being developed, ERDEC needs to analyze methods to integrate the technology (similar to vision system approach). Microphone and speaker technologies being researched under the RESPO 21 program could be integrated with AIPS' communication system. Research should be done on integrating this hardware with binaural processing using a neural network. For example, speech into a mask-mounted microphone would be transmitted to another soldier's binaural processing/neural network system. After processing and output to binaural speakers, the receiving soldier would know where the sound came from and how far away it was.

Design of the AIPS communication system needs to combine long range communications, soldier-to-soldier communications, and input from the soldier's immediate surroundings.

EQUIPMENT NEEDED FOR DEVELOPMENT:

Helmet and mask assembly.
Microphones and speakers.
Personal computer or other neural computing capabilities.

TECHNOLOGY AREA: SYSTEM CONTROLS

PROMISING TECHNOLOGIES:

Neural Networks

ASSUMPTIONS:

(1) AIPS will include a central processing unit.
(2) A soldier's individual computer processing capabilities will exceed AIPS requirements.
(3) Power will be available to operate such a system.

BACKGROUND:

AIPS will exploit the developments in computing speed and in neural network construction/implementation. Neural networks will be used in several processes of an AIPS, ranging from vision enhancement, to battle management, to virtually any other application where a "smart" processor would benefit the system.

RESEARCH NEEDED FOR DEVELOPMENT:

The basics for neural networking have already been developed. Low level neural networks are already being used in numerous applications. Current neural networks are simple with the more advanced networks being hampered by the processing speed. As processing speed increases, neural networks can become more complex. As we approach "real-time" computing the use of neural networks will increase, and the case of AIPS will become extremely beneficial.

Research will be needed into each application where AIPS could employ a neural network. The actual neural network process is quite similar from application to application, but varies by input, output, and the content of information the computer "learns". These parameters will need to be determined by ERDEC.

DEVELOPMENT APPROACH:

ERDEC needs to monitor advancements in system control components and sensors by periodically reviewing science and technology related journals. System input and output parameters need to be established for a neural network to be designed. ERDEC should also monitor developments in neural network computing technology.

EQUIPMENT NEEDED FOR DEVELOPMENT:

Personnel knowledgeable in the area of advanced computing and neural networks.

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